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Faculty of Engineering and Science

Aalborg University

AALBORG UNIVERSITY

Modelling correlates of public transportation and their association to active commuting

PhD Thesis

2014

Sune Djurhuus

FORSKNINGSCENTER FOR FOREBYGGELSE OG SUNDHED

Title: Modelling correlates of public transportation and their association to active commuting

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MANDATORY PAGE

Thesis title

Modelling correlates of public transportation and their association to active commuting

Name of the PhD Student

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Henning Sten Hansen, Professor, Dr.Scient. Mette Aadahl, MPH, PhD. Charlotte Glümer, MD, PhD.

List of submitted papers

I) Djurhuus, S., Hansen, H.S., Aadahl, M., Glümer, C. The association between access to public transportation and self-reported active commuting (submitted to International Journal of environmental Resources and Public Health).

II) Djurhuus, S., Hansen, H.S., Aadahl, M., Glümer, C. Building a multimodal network and determining individual accessibility by public transportation (in review, Environment and Planning B).

III) Djurhuus, S., Hansen, H.S., Aadahl, M., Glümer, C. Individual public transportation accessibility is associated with self-reported active commuting (submitted to Frontiers in Public health).

This thesis has been submitted for assessment in partial fulfilment of the PhD degree. The thesis is based on the submitted scientific papers which are listed above. Parts of the papers are used directly or indirectly in the extended summary of this thesis. As part of the assessment, co-author statements have been made available to the assessment committee and are also available at the Faculty. The thesis is not in its present form acceptable for open publication but only in limited and closed circulation as copyright may not be ensured.

Summary

Physical inactivity is one of the major risk factors for obesity, cardio-vascular diseases, some types of cancer and type-2 diabetes. Active commuting is receives an increasing attention in studies of physical activity. Most commuters need to travel from their homes to their work place or study every weekday. Choosing active travel modes (walking or cycling all the way or in combination with public transportation) rather than sedentary car-based transportation can provide routine-based physical activity to commuters during the week. Understanding how public transportation is associated with active commuting is thus important from a public health perspective. There is also an environmental benefit if more people choose to be active commuters due to reduced car-based commuting and related reduction in air pollution.

The aims of this thesis were to: 1) examine the association between different objective measures of access to public transportation including transit services and self-reported active commuting and investigate if the associations are modified by the individual commute distance, age and gender 2) construct a multi-modal public transport network and determining individual public transport accessibility and to 3) examine the association between individual public transportation accessibility and self-reported active commuting and investigate if the associations are modified by the individual commute distance, age and gender.

The study population comprised a subsample of participants from the Health Survey 2010 conducted in the Capital Region of Denmark. The survey was a cross-sectional random sample of Danish adults aged 16+ who answered a questionnaire including active commuting per day. The subsample used in this study consisted of participants between 16 and 64 years, working or studying, residing on the island of Zealand, having a commute distance < 200km and valid answers on active commuting. The self-reported data were combined with objective measures of public transportation and the built environment based on geographical data from the Geodata Agency and Rejseplanen.dk, and socio-demographic data from central registers from Statistics Denmark. The statistical analyses were carried out using multilevel logistic regression.

Distance to bus stops was negatively associated with active commuting and meeting recommendations of physical activity and density of bus stops, unique bus routes within walking distance and the number of different transport modes accessible within walking and cycling distance were positively associated with active commuting and meeting recommendations of physical activity. A weighted directed graph approach was used to build a multimodal network model integrating public transportation time schedules and walk links based on road network distances, thereby overcoming some of the simplifications of travel time often found in the literature. Individual public transportation accessibility calculated in the multimodal network was positively associated with active commuting and meeting recommendations of physical activity. The associations between the public transportation

measures and active commuting varied with distance, gender and age suggesting that the travel choice of participants with commute distances $\leq$ 10 km, women and those between 30 and 45 years are more influenced by access to public transportation and public transportation accessibility.

This study suggests that active commuting is influenced by both proximity to public transportation stops, the density and diversity of stops and services provided within walking or cycling distance. Based on the findings, the implication for future transport and health policy is to improve public transit services by increasing directness of routes and accessibility through improved access and linkage between services and keep travel costs at a rational level.

Danish Summary

Fysisk inaktivitet er en høj risikofaktor for fedme, kardiovaskulære sygdomme, nogle kræfttyper og type-2 diabetes. Forskere i folkesundhed er i denne sammenhæng blevet opmærksomme på aktiv pendling. De fleste, der pendler, skal hver dag transportere sig fra Deres hjem til arbejdspladsen eller studiet. Ved at gå eller cykle enten hele vejen eller i kombination med offentlig transport opnås vedvarende rutinepræget fysisk aktivitet igennem ugen. En bedre forståelse af, hvad der får folk til at være aktive, når de pendler, har derfor stor betydning fra et folkesundhedsperspektiv. Hvis flere vælger aktiv pendling fremfor bilen, vil det også have en gavnlig miljømæssig effekt gennem reduktion af luftforurening fra biler.

Formålene med dette studie var at: 1) undersøge sammenhænge mellem forskellige objektive mål for adgang til offentlig transport og selvrapporteret aktiv pendling og se, om disse sammenhænge ændrer sig med afstand til arbejde, alder og køn, 2) konstruere et multimodalt offentligt transport netværk for at beregne individuel tilgængelighed med offentlig transport, 3) undersøge sammenhængen mellem tilgængelighed med offentlig transport og aktiv pendling og igen se, om disse sammenhænge ændrer sig med afstand til arbejde eller studie, alder og køn.

Studiet bygger på en delpopulation af deltagerne i Sundhedsprofilen 2010, der blev udført i Region Hovedstaden. Sundhedsprofilen er et tværsnitsstudie med deltagere i alderen 16 år og op efter, som svarede på et spørgeskema bla. vedrørende daglig aktiv pendling og afstand til arbejde. Delpopulation i dette studie bestod af indbyggere fra Region Hovedstaden bosiddende på Sjælland, mellem 16 og 64 år, i arbejde eller studerende, med en pendlerafstand < 200 km og med valide svar på aktiv pendling. Den resulterende delpopulation var på 28.928 respondenter. De selvrapporterede data blev kombineret med objektive mål for adgang til offentlig transport og det bebyggede areal baseret på geografiske data fra Geodatastyrelsen og Rejseplanen.dk. Desuden blev der trukket individ baseret socio-demografiske data fra Danmarks Statistik. De statistiske analyser blev gennemført med brugen af multilevel logistiske regressionsmodeller.

Resultaterne fra denne afhandling viser, at afstand til et busstoppested er negativt sammenhængende med det at være aktiv pendler og at leve op til anbefalingerne vedrørende fysisk aktivitet. Tætheden af busstoppesteder, antal busruter indenfor gåafstand og antal offentlige transporttyper indenfor gå- eller cykelafstand var positivt sammenhængende med at være aktiv pendler og at leve op til anbefalingerne vedrørende fysisk aktivitet. En vægtet orienteret grafmodel blev brugt til at bygge et multimodalt netværk baseret på Rejseplanen.dk med integrering af rejsetider samt mulige skift i gåafstand. Individuel tilgængelighed ved hjælp af offentlig transport blev beregnet ved hjælp af det multimodale netværk. Individuel tilgængelighed var positivt sammenhængende med at være aktiv pendler samt at leve op til anbefalingerne vedrørende fysisk aktivitet. Pendleres rejsevalg er ifølge dette studie mest

influeret af adgang til og tilgængelighed med offentlig transport hvis man har ≤ 10 km til arbejde eller studie, er kvinde eller er mellem 30 og 45 år.

Resultaterne fra dette studie antyder at aktiv pendling er påvirket af nærheden til offentlig transport, tætheden, antallet af ruter og adgang til forskellige transporttyper indenfor gå- og cykelafstand. Baseret på disse fund bør fremtidig transportplanlægning fra en sundhedsvinkel højne tilgængeligheden med offentlig transport gennem bedre adgang og bedre forbindelser samt holde rejseudgifterne need, så offentlig transport er konkurrencedygtig med bilen.

Preface

This PhD Thesis was carried out during my employment at Aalborg University, Development and Planning in Ballerup and later in Sydhavnen and at the Research Centre for Prevention and Health in Glostrup.

First of all, I wish to thank my supervisors, Charlotte Glümer, Henning Sten Hansen and Mette Aadahl for your scientific expertise, constructive ideas, encouragement and your patience with my wild ideas and endless programming. A big thank you to Charlotte Glümer for giving me the unique opportunity of conducting this thesis and a special thanks to Mette Aadahl for always leaving the door open and taking the time for numerous (lost count) scientific discussions, guidance and (while trapped in your office) for listening to all my bad jokes.

I wish to thank my colleagues at the Research Centre for Prevention and Health for creating an inspiring atmosphere with lots of great scientific discussions as well as laughs, sharing stories about the kids and for feeding me endless amounts of cake and candy. Thanks to my roommates, Solvej, Julie, Mette, Sine, Malene and the next door office Lene, Rikke and Tea for your support and for coping with my frustrations and talkative nature. Special thanks go to Gert Gløgg for trying to keep me fit playing table tennis outdoors throughout the year. Last but not least thanks to the other hard working PhD fellows Runa, Tea and Solvej for keeping company in the many weekends spent in Glostrup.

A big thank you to my colleagues at Aalborg University, Thomas, Anders, Morten, Rikke and Henning, for an always enjoyable time in the short periods I spent in the office and at our team meetings with various culinary themes. I'll buy the next one.

I am very grateful for all the support, patience and understanding from my family and friends.

To my lovely daughter Lily

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1. Introduction

Active commuting (walking or biking for transportation) is receiving an increasing attention in studies of physical activity. Most commuters need to travel from their homes to their work place or study every weekday. Choosing active travel modes rather than sedentary car-based transportation can provide routine-based physical activity to commuters during the week. The term “active commuting” refers to active travel modes such as walking or cycling to and from work or study or using public transportation which involves some walking or biking to public transportation stops, transfer walks and walking or biking to the end location (1). Cross-sectional studies find that active commuting by public transit use is significantly associated with accumulating more physical activity daily than transit non-users (2-4) and active commuters are more likely to reach 10 000 steps/day compared to car users (5;6). Likewise, Besser et al (7) find that 29% of transit users achieve more than 30 minutes’ walking to/from transit per day.

Physical inactivity is one of the major risk factors for obesity and non-communicable diseases such as cardio-vascular diseases, some types of cancer and type-2 diabetes. Globally, an estimated 5.3 million deaths per year can be attributed to physical inactivity and 6 – 10 % of all deaths from non-communicable diseases can be attributed to physical inactivity (8). This is even higher for specific diseases, e.g. 30 % for ischemic heart disease (9). In Denmark the estimated population attributable risks associated with physical inactivity are 5.8% for coronary heart disease, 7.2 % for type-2 diabetes and 9.4 % for premature mortality. Accordingly, physical inactivity constitutes one of the largest challenges to public health. Engaging in active commuting has thus the potential to provide substantial positive health effects. Furthermore there is an achievable environmental benefit when more people choose to be active commuters due to reduced car-based commuting and related reduction in air pollution. Air pollution from vehicle emissions alone has been measured to account for 20 premature deaths in the Capital Region of Denmark in 2010 (10). Denmark has a high prevalence of active commuting. Results from the Danish National Travel Survey 2011 (11) showed that 76 % of all commute trips < 5 km were carried out either walking or cycling and accounted for 48 % of all commute trips < 10 km. Public transportation trips accounted for 17 % of all commute trips at commute distances more than 20 km (11).

Research has established that the physical environment plays an important role in active commuting and associations have been found between active commuting and different objective measures of the built environment, walking and biking facilities, street connectivity and proximity of destinations (12-14). In relation to public transportation and active commuting, a few studies have found that the distance to the nearest transit (12;15) is negatively associated with active commuting, and that density of stops (16-19) is positively associated with active commuting.

Additional relevant measures of the access to public transportation such as service frequency, route variation and meaningful destinations (20) have only been investigated in a few studies in relation to active commuting (12;21). Only one of these studies finds a positive association between the nearest bus stop service frequency and active commuting (12). Meaningful destinations are often used in transport planning and urban form studies where it is an integrated part of the term accessibility (22). Accessibility by public transit describes how efficient the public transport network is in bringing people to their destinations often within a given time frame. Accessibility adds travelling to the access measures and thereby integrates how easy it is to commute using the public transit. Research of accessibility in relation to active commuting is sparse. One study (23) has investigated transit accessibility in relation to active commuting by evaluating if respondents can reach the major city centers, and find that transit accessibility is significantly associated with walking energy expenditure.

Previous studies of association between measures of public transportation and active commuting are mainly from the US (15;16;18;23-26) and Australia (19;27;28) whereas only a few studies exist from the other continents (12;21;29). It is not known whether these findings can be applied to a Danish context having different settings. The urban environment, public transportation system and travel behaviour differ between countries so the associations might be different in Denmark. The studies focus to a large extent on the distance to nearest public transportation stop or density measures to describe access to public transit. Those living in urban areas may have a high number of stops within walking distance and other transit stops may offer better services than the nearest stop. Although it is acknowledged that transit service characteristics and the accessibility by public transit play an important role in commuters' travel preferences, very few studies have examined such measures in association with active commuting. In order to understand better how public transportation influences individual active commuting, there is a need for studies that examine a wider range of public transportation measures and include transit service characteristics and accessibility. Ultimately, this knowledge can help researchers and planners within transportation and public health to target future interventions aimed at increasing active commuting.

1.1 Aims

Based on the hypothesis that easy access to public transportation and high accessibility by public transportation play an important role in active commuting, this thesis aims to:

1) Examine the association between different objective measures of access to public transportation including transit services and self-reported active commuting and investigate if the associations are modified by the individual commuting distance, age and gender. (Paper I).
2) Construct a multi-modal public transport network to calculate individual public transport accessibility (paper II).

3) Examine the association between individual public transportation accessibility and self-reported active commuting. Furthermore to examine whether the associations are modified by the individual commute distance, age and gender (Paper III)

2. Background

2.1 Physical activity and health

Physical activity has been defined as any bodily movement produced by skeletal muscles that require energy expenditure (30). It is a multidimensional behaviour performed in different domains e.g. leisure time physical activity, active transportation (e.g. walking or cycling), occupational (i.e. work) and household chores, see Figure 1 (page 19). Engaging in physical activity is important from a health perspective for the reason that physical inactivity is a major risk factor for obesity, certain types of cancer, type-2 diabetes and cardiovascular disease (8;31-33). Furthermore a physically active lifestyle has positive physical and mental health benefits to both children and adults (31).

A number of evidence-based physical activity recommendations have been published by global and national health authorities in recent years (31;33;34). In 2010 WHO launched global recommendations on physical activity for health (33). The recommendations for adults aged 18 to 64 years are to engage in 150 minutes of moderate-intensity physical activity during the week and increase their moderate-intensity aerobic physical activity to 300 minutes per week, or engage in 150 minutes of vigorous-intensity aerobic physical activity per week for additional health benefits. In addition, studies have suggested the alternative that adults should walk at least “10,000 steps per day” to maintain optimum health (35;36). In Denmark, the recommendations for adults aged 18 – 64 years are to engage in 30 minutes moderate-to-vigorous intensity physical activity daily in addition to short-term daily activities. If the 30 minutes are split up, the activities should last for at least 10 minutes per interval. Furthermore it is recommended to engage in high intensity physical activity for at least 20 minutes twice a week to maintain fitness level and muscle strength (34).

A population based survey conducted by the Danish National Institute of Public Health showed an increase in moderate-to-vigorous physically active in leisure time from 1987 to 2010 (37). The increase applied to all age groups and both genders. This is supported by a study including two cross-sectional health surveys in the Capital Region of Denmark finding a trend showing an increase in the daily amount of moderate-to-vigorous intensity physical activity (excl. active commuting) from 2007 to 2010 as well as an increase in the proportion of active commuter from 2007 and 2010 (38).

2.2 Active commuting: A contribution to physical activity

Although active commuting is only carried out in short periods during the day (figure 1) it has been shown to contribute quite markedly to people´s daily total physical activity. Active commuting includes walking or cycling all the way to and from work or study or in combination with using public transportation. Morabia et al. (39) compared commuting an identical route by public transport and car respectively, and found that public transport commuters expended 622 kcal more (in five days) compared to car-based commuters. Lachapelle et al. (2) found that frequent public transit commuters accumulated significantly more moderate-intensity physical activity per day (5 - 10 minutes) compared to non-public transport users. Smaller studies in university and workplace settings using accelerometer measurements have found an association between active commuting and a higher weekly total physical activity level (40;41). In addition, studies with pedometer measurements have found that active commuters walk significantly more steps per day than non-active commuters (5;6). This is supported by a large cross-sectional study performed by Sahlqvist et al. (3) in the UK, which found that those reporting commuting solely by active modes or active commuting in combination with public transportation or car were significantly more active than those who used only motorized modes of transport. Duration of recreational physical activity was not different in active and non-active commuters (3). Similarly, Saelens et al. (42) found that transit users had higher daily levels of total physical activity but did not differ in non-transit related walking or non-walking physical activity whereas Terzano & Morckel (2011) (43) found that active commuters in three universities in USA also spent more time on recreational physical activity. Using public transit for all purposes has also been associated with significantly more walking per day (8.3 minutes) (4) and 29 % of transit users in a cross-sectional study from USA were found to achieve the recommended 30 minutes of walking per day (7).

2.3 Active commuting and health outcomes

The benefits of active commuting are evident when looking at associated health outcomes. In a Danish study, bicycling to work was associated with approximately 28 % decreased risk of all-cause mortality (44). A meta-analytic review of prospective cohort studies conducted by Hamer & Chida (45) found a significant protective effect (RR = 0.89) of active commuting on cardiovascular outcomes with a stronger protective effect for women (RR = 0.87 vs. 0.91 for men). Active commuting by public transportation, walking or biking have also been found to be associated with a significantly lower risk of being overweight (RR = 0.63 - 0.85) (46), and a significantly lower risk of being overweight (RR = 0.49) or obese (RR = 0.34) in men cycling to work (47) or walking or cycling (RR = 0.50) (48), but not in women. Furthermore active commuting may have a positive effect on diabetes prevention (46;49;50) and has been associated with higher physical and mental wellbeing (51).

Besides providing health benefits to commuters, active commuting has an environmental benefit through reducing car congestion and related air pollution and carbon dioxide emissions (23). Understanding determinants of active commuting is thus important in relation to planning environmentally sustainable cities and improving public health.

2.4 Theories of health behaviour

Research of travel behaviour (including active commuting) has been conducted within the field of transportation, and urban design and planning and has more recently found implications in health research. Identification of factors that influence, facilitate and promote active travel is important for the success of future interventions. The complex nature of health behaviour and the large number of possible influences have required the use of theoretical behaviour models as a basis for understanding and identifying associations and possible causal links.

Behaviour models focus on individual intention and attitudes and social influences from friends and family. The theory of reasoned action and theory of planned behaviour have been extensively used in relation to a variety of health topics (52). The theory of planned behaviour has been used in a number of intervention studies to change travel behaviour. Reduction of fare prices and more direct routes to the city centre from a university campus (53), free tickets in addition to information on bus services (54;55) and marketing of the benefits of bus travel and disadvantages of car-based travel (56) were shown to increase the use of public transportation.

Recently, the broader ecological models have gained increasing attention for attempting to describe health behaviour. The ecological model is based on nested structures where the individual behaviour is influenced by a number of scaled environments. Bronfenbrenner (57) identified five of these socially organized levels (micro-, meso-, exo-, macro-, and the chrono-environment) and suggested that all levels need to be taken into account in order to understand human development.

In recent years, the socio-ecological model approach has been applied to studies of physical activity and active living (58;59). Individual physical activity is influenced on multiple levels e.g. the intrapersonal level, the physical environment in which the individual lives, the social-cultural environment surrounding the individual, and policy factors, see figure 1. Other conceptual frameworks, in line with the socio-ecological model, have identified similar important characteristics of the physical environment that influence the different domains of physical activity (60-64). The physical environment is to some extent modifiable and environmental interventions in combination with individual interventions may be more effective than individual based interventions alone (60;65).

Active commuting is about getting from home to work or study and the choice of transport mode may be influenced by the directness of routes (road network), pedestrian paths and sidewalks, cycle paths, access to public transportation, transit services and parking facilities. These are features often referred to as the ‘built environment’. There are two main methods to assess the built environment features: subjective or objective assessment. Subjective methods use self-reported perceptions of the surrounding neighbourhood as measures whereas objective methods use geographical (spatial) data to create measures that characterize the built environment. This thesis focuses on the objective measures.

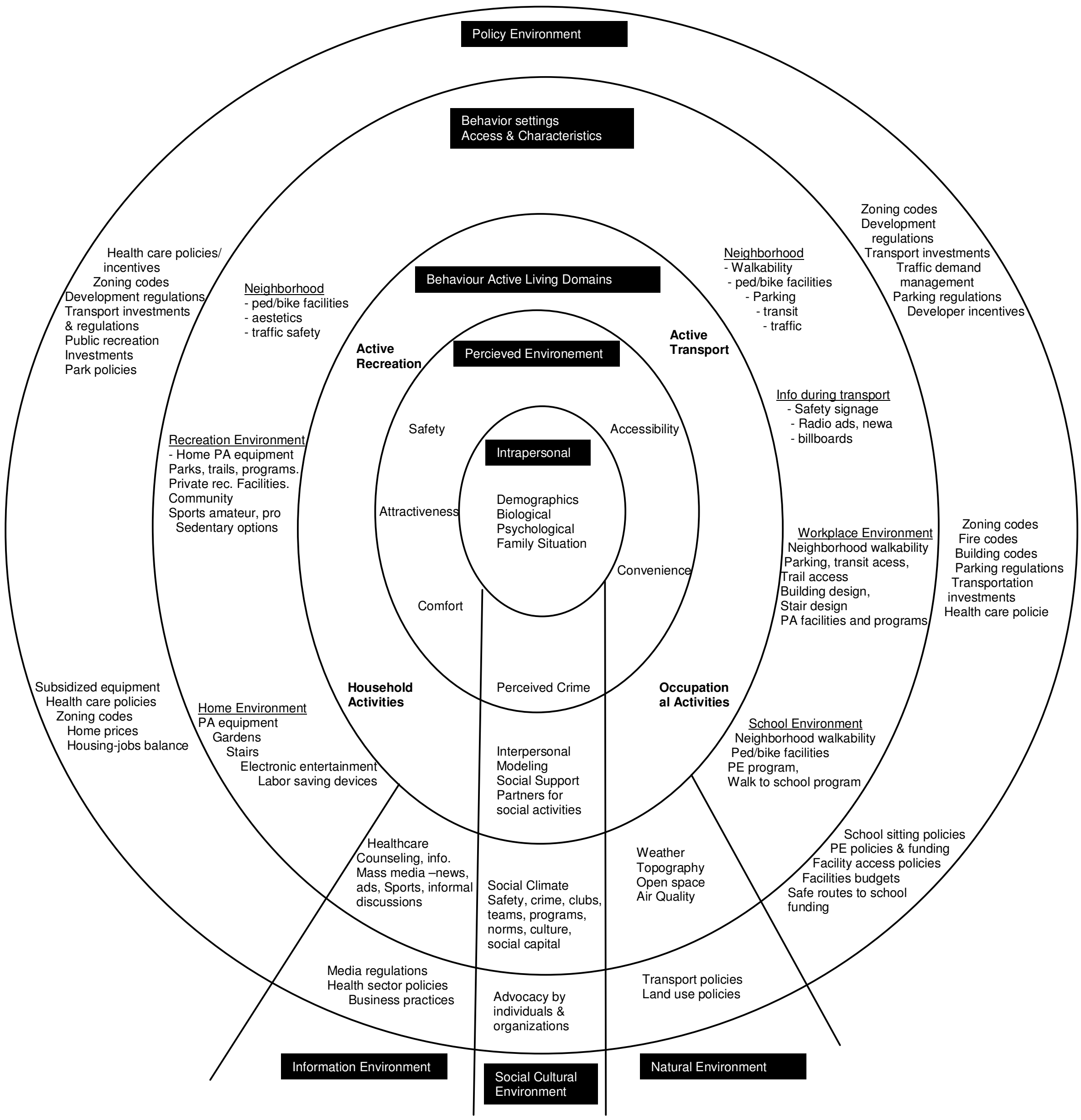

Figure 1 The socio-ecological model of four domains of active living (based on Sallis, 2006) (58).

2.5 Objective measures of the physical environment and association to active commuting

Integrating geographical (spatial) data and spatial computation methods handled in a Geographical Information System (GIS) have enabled researchers to develop, measure, and represent features of the built environment. GIS software comes with a suite of tools to calculate precise distance measures, perform spatial joins between point-based data (e.g. transit stops) and area-based data (neighbourhood) for density expressions e.g. number of transit stops within walking distance, and to perform network analyses to calculate the accessibility to opportunities by any transport mode.

A number of studies have investigated the association between different measures of access to public transit and active commuting. These studies are presented in Appendix 1. In summary the studies are mainly cross-sectional studies from USA (15;16;18;23-26) and Australia (19;27;28). The age range of the study populations is between 16 and 70 years. The study population sizes vary from smaller studies (< 500) (18;19;21) to large-scale studies (> 5000) (15;23;26). Three studies are targeted towards a specific population group; African-American women (15), rural living Japanese women (21), and 50-75 year old English speaking adults in the USA (16). A short description of the most common objective measures used in the studies to describe the characteristics of public transportation, and their association to active commuting is presented in the following sections.

2.5.1 *Distance measures*

Proximity is a widely used measure to describe the access or availability of public transportation, parks, cycle paths etc. In GIS, the distance can be derived as simple Euclidean distance, network distance, or alternatively as the time spent along a road network. The network distance is usually calculated by using Dijkstra's algorithm (66) for finding the shortest path between the origin and the destination. If an area has many cul-de-sacs and a low number of four-street intersections, the Euclidean distance between an origin and a destination underestimates the "real" distance when walking or biking on the road network. Network distances are better measures of real walking distances although movement is restricted to walking on the network. A high proportion of walkable (crossable) green areas or street crossings not registered in the network data results in the network distances overestimating the "real" walking distances (67).

The access to public transportation has been measured as the network distance to nearest bus stop from home (12;18;19;23;27;29), nearest train station from home (12;18;19;23;27) (Kamada et al. (21) uses Euclidian distance to bus and train), or nearest public transportation stop from home (25;27;28). Some of the studies categorise the distance into having a bus stop within 400 and 1500m from home (27), presence of a transit stop within a 400m circular buffer (28), or living within 450m or between 450 and 1000m from a transit stop (25). Only some of the studies find significant associations between the distance measures and active commuting or use of public transportation. A greater distance to the nearest bus stop is found to be associated with less utilitarian walking (15) and an increase in the energy expenditure from walking (23). Greater distance to the nearest bus stop and rail station is found to be associated with lower odds for walking for transportation ≥ 150 min/week (18), and lower odds for using public transportation (12). Residing within 400m from a bus stop and within 400m and 1500m within a rail station is found to be significantly associated with regular walking for transport (27).

2.5.2 *Density measures*

Density measures are often derived from distance measures and are used to express the number of transit stops or other destinations (land use mix such as shops, food stores etc.) within a given distance, time, or per area. It is a measure of opportunities, their concentration, and variety within walking distance. The term service area is often used by transit planners in modeling the access coverage or area within which people are willing to walk to the public transportation stop. The size of the so-called buffer zones used in transport planning around bus stops is typically 400m and 800m around train stations (68). To some extent these buffer sizes have been adapted by the studies of association between access to public transportation and active commuting to measure a number of identified built environment characteristics. The studies count number of bus stops or transit stops within 400 m (1/4 mile) (18;19), 500m (29), 800 m (½ mile) (12;18), and census block level (16). As alternatives to the count of stops, Hoehner et al. (24) use a 400 m buffer zone to measure the percentage of street segments with a bus or other transit stops and Coogan et al. (15) uses an 800 m buffer to measure the length of bus routes to express access to busses. The density of bus or transit stops has been shown to be positively associated with walking for transport (16;18;29) and meeting recommendations on physical activity (16;18).

2.5.3 *Public transport service characteristics*

To a large extent the studies listed in Appendix 1 only use the location based measures listed above to describe the attractiveness of public transport as commuter mode. Stone and Mees (2010) (20) comment that attractive service frequencies and operating hours for multiple destinations are important features of public transportation. Data on public transportation services need to be integrated with the public transport stops to compute these kinds of measures. Lack of data is perhaps the reason why these measures are not researched to a broader extent. A few studies have measured the service frequency at nearest stop (12;21;26) and number of routes within 800 m network distance from home/work (12). Kamada et al. (21) define a bus convenience index based on distance to nearest bus stop and service frequency. Findings show that lower bus frequency is associated with lower odds of public transport use in the UK study (12). However, more studies that include public transportation service characteristics are warranted.

2.5.4 *Connectivity*

Street connectivity is widely used in studies of active commuting and relates to directness and availability of alternative travel routes through the street network (69). In a public transportation context it measures how easy it is to reach a public transport stop. The measures are often density based using the same buffer distances as the density measures. Grid-based networks have high connectivity and shorten the travel distance between an origin and a destination, whereas many dead-ends in the network restrict direct travelling. A number of connectivity expressions are used in the literature in relation to active travel both from transport planning and public health. Transport geography uses a number of different link-node ratio indexes to describe connectivity (α, β, ɣ, etc.) (70;71). Other widely used expressions are the block size (15;72), block length (28;73), street density (12;23;29), number or proportion of three and four-way intersections (12;14-16;26;29;73;74) and the ratio between route length and Euclidian distance (13). Connectivity is often used as a confounder in the association between the built environment and active commuting. It has been found to be positively associated with public transport use (12) and for choosing bike over car for transportation (14).

2.5.5 *Land use mix and walkability*

Land use mix is a parameter describing the urban form and the distribution of different land use opportunities such as residential, retail, entertainment, office, and institutional (75). It is measured extensively in studies of physical activity and the environment as a proxy for how attractive the neighbourhood facilities are for a number of activities. Only two of the studies in Appendix 1 have not included some kind of land use measure in addition to the public transportation measures (19;25).

Walkability is an index describing how walkable or conducive for walking an area is. It is a composite of a number of components such as net residential area, retail area, connectivity and land use mix (75). Whereas walkability is widely used in studies of leisure time physical activity, a few studies only include walkability in association with active transportation (28;76-79). They find that higher walkability is associated with more walking (28;76-79) and cycling for transportation (76-79).

2.6 Individual socio-demographic confounders

Health and travel behaviour research recognise that individual factors such as demography, health, attitudes, economic status and social relations affect the associations between the built environment and physical activity. Individual socio-demographic factors frequently included in Appendix 1 are age, gender, ethnicity, education, income, employment, car ownership, marital status, and children in the household. General health measures included are BMI, general health state, limiting illness, and chronic diseases. Age, gender, income, car ownership and employment have been found to affect travel mode choice (80). Other studies have found that there is a higher prevalence of using public transportation in younger age groups (46;81). The associations between SES (socio-economic status) indicators with walking or cycling for transport are not clear. Some studies show a negative association between high SES and walking for transport (77;82). Cerin et al. (83) found that individual level household income was negatively related to weekly minutes of transport. Sallis et al. (84) did not find any association between income and walking for transport. Different measures of SES may lead to differences in findings.

2.7 Area-based Socio-demographic confounders

The social environment (contextual factors) such as neighbourhood socio-demographic and cultural factors may influence the individual choice of health behaviour. Population density is often used as a proxy for the opportunity for social interaction whereas area level SES (income) is used to describe the social norms, social- and economic capital and culture in the area the individual lives in. Lower area SES has been found to be associated with higher levels of walking for transport (77;82;85). Van lenthe et al. (86) found that lower SES areas were associated with higher likelihood of not walking or cycling for transport. However, Lachapelle et al. (2) found no association between area level income and public transport use.

2.8 Accessibility

Although access is an important part of choosing public transportation for commuting, it does not describe how effective the transport network is for transporting the individual to destinations i.e. the transport part of commuting. Theories on travel behaviour have long been of interest to transport and urban planners. Their focus has been on studying how transport networks (car-based and public transportation) support reaching destinations or opportunities such as jobs and how it influences travel mode choice (87-93). The term accessibility (used widely) has been defined as the potential of opportunities for interaction (94) or the ease with which people can reach their destinations or activity sites (22). It is determined by the spatial distribution of destinations, the ease of reaching each destination, and the magnitude, quality and character of the activities found there (95).

A substantial amount of accessibility measures has been developed based on different travel behaviour theories and the aggregation level of data. Accessibility measures are often based on a number of components; land use (jobs, shops, transit), transportation (transport system), temporal (peak or off-peak time), and the individual (needs, demography, social status) (96). Four groups of accessibility measures have been defined and used widely in the literature and are worth mentioning in the context of active commuting (95;97;98).

The first group of measures is the **"cumulative opportunities measures"**, which count the number of opportunities reachable within a given travel time or distance or general cost. Potential destinations or opportunities are usually weighted equally. The measure is often referred to as contour or the iso-chronic measure and is widely used in planning. It is a simple measure to compute, but it is sensitive to the cut-off travel time or distance. Density of transit stops within walking distance is a simple example of a cumulative opportunity measure.

The second group is **"gravity based measures"** that are based on the denominator of the gravity model for trip generation. This potential model was first derived by Hansen (1959) and incorporates weights on the opportunities or destinations often as a function of travel time or quantity as a proxy for their attraction. Travel time impedance is often used in a negative exponential function such that the larger the distance to an opportunity, the lower the impact on the accessibility measure.

The third group of measures is based on **"random utility theory"** and consists of the denominator of the multinomial logit model (95). Every location is given a utility value and the likelihood of choosing an opportunity depends on the utility of that choice compared to the utility of all choices. The discrete choice theory seeks to explain the relation between urban form and travel behaviour (99). The individual makes a choice regarding travel mode, based on the utility of that choice of mode relative to the other modes. Utility could be travel cost, travel time or convenience. Pirie (100) denotes that the strength of utility-based measures is that they enable measuring accessibility at the individual level based on individual preferences and in this way capture the differences in preference.

The fourth group is **"space-time measures"**. The space-time theory was first introduced by Hägerstrand (101). The travel in space and choice of activity depends on the individual's mobility and constraint by time. The integration of time is a strength since many activities and thereby accessibility are time dependent. A simple look at a public transportation time schedule reveals that transport services vary markedly from peak to off-peak hours which have an immediate effect on accessibility.

2.8.1 *Public transportation accessibility – integration of individual travel time*

Many of the older studies on public transportation accessibility calculate travel time between zones or neighbourhoods to represent the individuals living in the zones (88-90;93;102). The studies have used origin-destination matrices based on shortest path or distance often derived by planning staff (87). Demand for a sustainable solution within traffic and urban planning together with an increased availability of more disaggregate data such as parcel-level data, available transit schedules from web sites or travel planners, together with high performing GIS software have generated a growing interest in creating individual based public transportation accessibility measures using multimodal network analyses (103). The individual approach seems logical, since ridership decision is based on the individual's personal criteria such as the cost, distance, access and services provided (98;104;105). Moreover, the public transit accessibility measures seek to integrate the temporal differences in services during the day (rush-hour, off-peak). This follows the theory of the space-time accessibility measures, in which activities are influenced by the individual's needs and the time of day (101).

GIS has been used extensively in the literature to measure public transportation accessibility. Authors have either developed tools to create isochrones maps of accessibility (106;107), created applications integrated with the ArcGIS (ESRI) platform (87;98) or used GIS programs such as ArcGIS (92;103;108) or Accession (109) to create accessibility catchment areas. In addition to the GIS based approaches, Salonen and Toivonen (92) created three models of accessibility. In the first two models they use ArcGIS to calculate the accessibility like the studies above. In their third "advanced" model, they use the API of the local travel planner (Helsinki, Finland) and calculate the accessibility based on the official up-to-date public transport schedules.

The main challenge of calculating individual public transportation accessibility lies in how to handle the temporal component. Some studies integrate detailed transit schedule information in their analyses (87;92;98;103;108;110) while others rely on average travel speeds assigned to the whole route (106;107;111). Standard GIS software does not have capabilities to handle the temporal variation in transit services directly, so average travel times based on routes are often (necessarily) applied to the links between the stops. Although the access distance is important when using public transportation (112), the studies listed above often ignore this or do not report how this is integrated. Some of the studies take into account accessing other stops than just the nearest one since the nearest stop might not provide the timeliest connection to a given destination (92;98;107).

The different parts of the travel with public transportation are calculated in a number of ways. Wait time at initial stop is in most studies simplified to one half the headway time (time interval between departures) (103;107;109) or a fixed number of minutes (108;111). In other studies, the wait time is integrated from the transit schedules (87;92;98). When schedules are not integrated, the standard procedure used for calculating in-vehicle travel time is to use the average travelling speed calculated from time spent on the whole route divided by the route length (106;107). Transfers between modes are often ignored (106) or handled in the same way as wait time (frequency of service) (107;108). Using transit schedules enables calculation of transfer time as the elapsed time between arrival and the departure of a new service. A study from the Netherlands by De Jonge and Teunter (113) showed that integrating walk transfers into the multimodal network reduced total travel time. So this is an important feature of travelling. Finally only one study defines the distance individuals can walk from the end stop to a location (87).

In their comparison between using the simplifications of travel time mentioned above or integrating time schedules, Salonen & Toivonen found that using half the headway time as a surrogate for transfer related wait time, clearly underestimates travellers' ability to optimize their journey. Especially short trips were sensitive to this and they conclude that transfers based on true schedules are much shorter than half the headway. Their results also showed that the travel time is much more sensitive to the underlying model than travel distance.

3. Materials and methods

3.1 Study Area

The study area is the Capital Region of Denmark, see Figure 2. The area covers 2,561 km^2 (the region is 1,973 km^2 excluding the island of Bornholm) and the population in the Zealand part is approximately 1.6 million (2010) (Statistics Denmark). The main urban areas are the Copenhagen metropolitan area (1,181,239 inhabitants) and 7 other smaller cities (20 – 50,000 inhabitants).

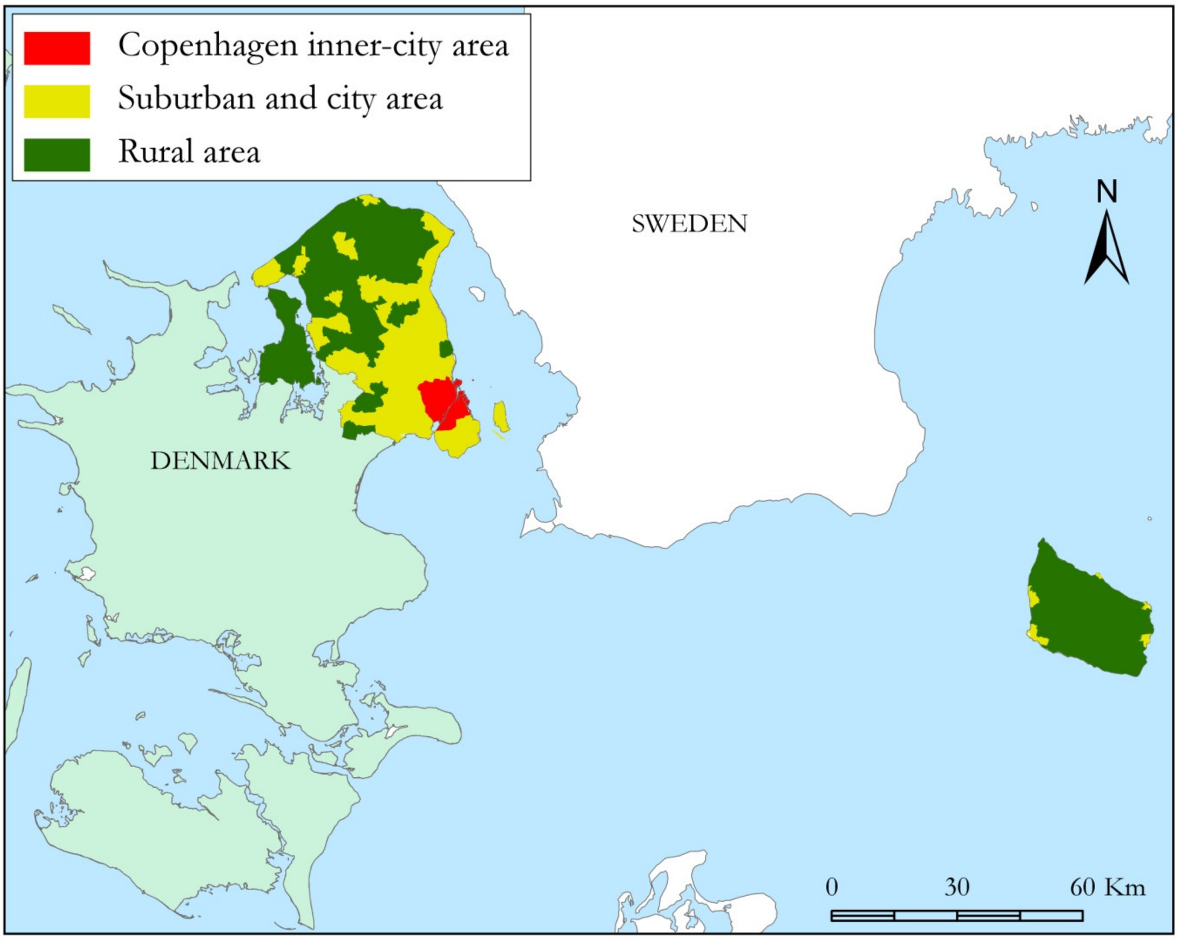

Figure 2 Overview of the study area including Bornholm (the Island to the east). Parishes have been divided into Copenhagen inner-city area and suburban and city areas having a population density of > 250 inh./km^2 and a rural area with a population density of < 250 inh./km^2.

The urban transport system and the public transport system development in the Region is shaped by the strategic urban development plan “The Fingerplan” from 1947 (114). Pressure on the capacity of the local public transport network that consisted of busses, trams and railways led to the identification of five urban development corridors around existing or planned railway lines. The so-called S-train network was developed as an electrified rapid rail transit to Copenhagen’s Central Business District (CBD) (115) from the five fingers.

3.2 Study population

The study population consists of participants from a cross-sectional questionnaire survey conducted in the Capital Region of Denmark from February to April 2010. The survey was part of the Danish National Health Survey 2010 (116). Using computer generated random numbers, random samples of residents 16+ of age were drawn from the Danish Civil Registration System (CPR). The sample size for each municipality was 2,450 persons. Due to the population size, the sampling size in Frederiksberg Municipality was increased to 4,500 persons and Copenhagen Municipality was divided into ten units each treated as a municipality in the sampling process, see Figure 3.

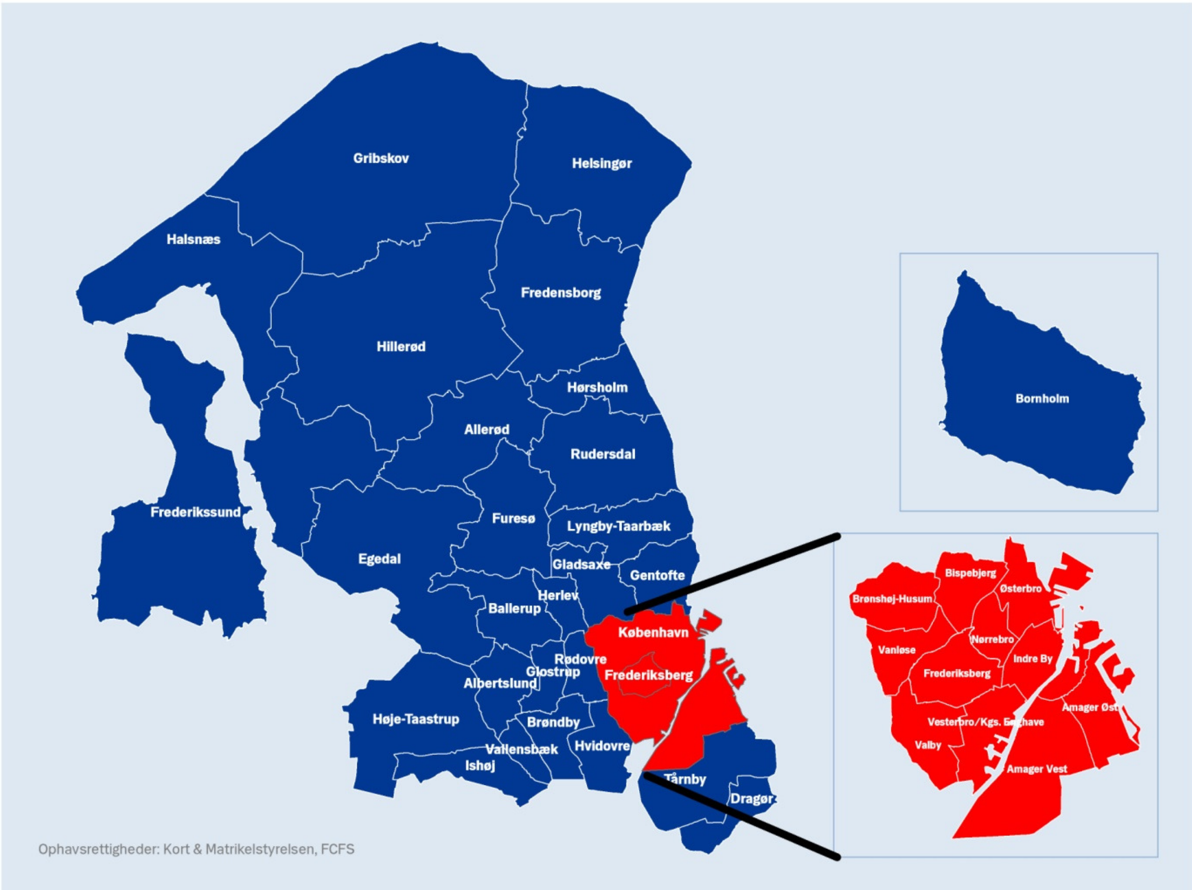

Figure 3 Overview of the municipalities in the Capital Region of Denmark and the division of Copenhagen municipality into 10 city units

The total sample included 95,150 individuals from the 29 municipalities. Individuals were invited to participate in the survey by mail and were asked to fill in a questionnaire, paper version or online. The response rate was 52.3% (N=49,806). The survey was reported to and approved by the Danish Data Protection Agency. Approval from the regional Committee on Health Research Ethics was not necessary as no human biological material was included in the data collection.

Respondents from the island of Bornholm were excluded due to the isolation of the island from the metropolitan area public transport network. The study population selected for this study was restricted to 16 to 64-year-old respondents living on the island of Zealand, either under education or working, having a commute distance of more than 0 km but less than 200 km and reporting valid data on the outcome variable. Figure 4 shows the different exclusion criteria and the resulting sample size.

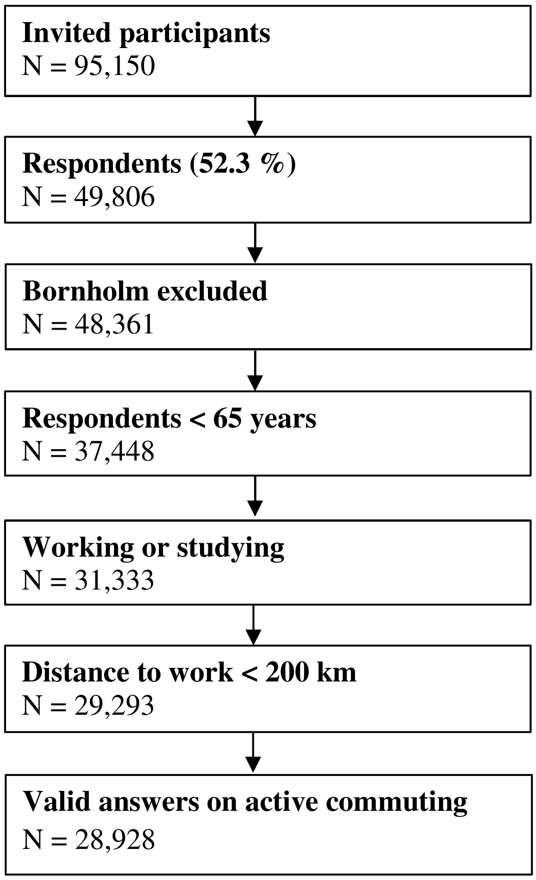

Figure 4 Flow diagram of the exclusion criteria used to select the study population.

The population used in articles I and III is 28,928 individuals. The population size in paper II is 29,447. People working below 200 hours per year were excluded before running the analyses in paper I and III. The respondents' home addresses were geo-coded using address-matching to the official address register from the Danish Geodata Agency. The geocoding enabled the linkage to other geographical data and geographical analyses based on individuals.

3.3 Data Sources

The study uses a number of databases linking the survey respondents to the Danish nation-wide registers and spatial databases. The data sources and preparation for use in the papers are outlined below.

3.3.1 *Central registers*

Data from the national central registers were obtained from Statistics Denmark. A short description of the registers they origin from is given below.

All of the respondents have a unique Danish civil registration number (CPR) which is registered in The Danish Civil Registration System (CRS) (117). The CPR number consists of 6 digits indicating date of birth, followed by 4 digits indicating the gender of the individual. This administrative register was established in 1968 and includes information on place of birth, vital and civil status, parental links, spouse and place of residence (address). The CPR number can be used as a unique identifier to link to other registers. Age, gender and population density were drawn from CRS and used in papers I and III.

Education level, used in paper I and III, was drawn from the Danish Population Education Register (PER). It contains information on individuals' highest completed education for 96.4% of the Danish population aged 15-69 (2008) (118).

Median income, used in paper I and III, was drawn from the Danish Income Statistics Register that contains a large amount of information such as income, wages, taxes, pension, fortune and socioeconomic status along with a number of demographic variables (119).

Employment used to select the employed part of the study population was drawn from the Register-based labour force statistics that contains information on the Danish population's affiliation to the labour market (120).

3.3.2 *www.Rejseplanen.dk*

Rejseplanen.dk is a travel planner and the official search engine for all public transportation in Denmark. The database contains information on transport mode, operators, geographical location of transit stops, routes, time of operation, time schedules etc. The data were received in a number of text-files in HAFAS raw data file format covering all public transportation modes in Denmark. The services and their time schedules covered the period of the questionnaire from February to April 2010. The text-files were stored as separate tables in a MS SQL SERVER 2008 R2 database, © 2014 Microsoft. Based on documentation received from Rejseplanen.dk, the different tables were joined by unique identifiers to create a master table. The table contains information on service operators, transport modes, operating days, routes, time schedules, and geographic location of each transit stop in Denmark. The master table was used to build the multimodal network in paper II and to create measures of public transportation in paper I and III.

3.3.3 *Kort10*

Kort10 from the Danish Geodata Agency is a topographic base map collection in vector format. The data collection is object based and the thematic layers are divided into 9 classes; administrative boundaries, buildings, built-up area, addresses, traffic (road network), technical themes (sport facilities, graveyards), nature themes (forest, wetland), hydrology (lakes, rivers), and topography (contour lines). The data were stored in a ArcGIS 10.1 file-geodatabase (Redlands, CA: Environmental Systems Research Institute). The road network was used to create proximity and density measures to transit stops in paper I as well as access and transfer walk links in paper II.

3.4 Building the multimodal public transportation network

The proposed multimodal network model in this study (Paper II) is conceptually a weighted directed graph having time between stops (in-vehicle, access/egress time, wait time and transfer time) as the weight and only allowing one-way traffic (121). The two-dimensional design was controlled by topology rules based on time. Time is thus controlling which vehicles can be entered and which interchanges or transfers that can be conducted at a given time. The Information from Rejseplanen.dk has been integrated into the model so that all travel time components are in accordance with the schedules. In addition to the public transportation schedules, the distance to public transportation stops from individual home addresses (see section 3.7.1) as well as distances for walk transfers between stops/stations, were calculated using the road network theme from The Danish Geodata Agency and the origin - destination matrix tool in the Network Analyst Application in ArcGIS 10.1. The walk links were subsequently integrated into the data from rejseplanen.dk to form the multimodal network. The different components of travel time and their implementation into the network are shown in Figure 5.

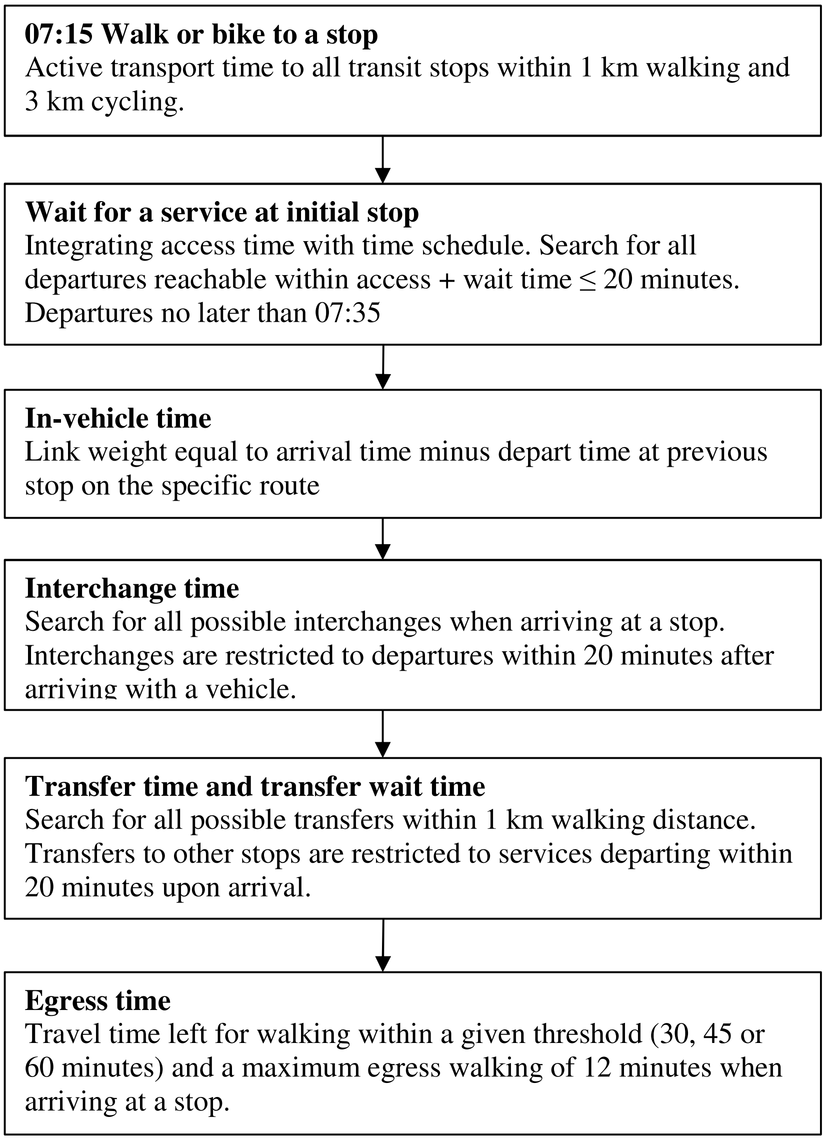

Figure 5 The different travel parts that need to be integrated into the multimodal public transportation network to calculate individual accessibility area.

To overcome the challenges of integrating all temporal components of travel time without using simplifications, the original stop was split into a number of stops equal to the number of routes arriving at a given stop, see Figure 6. Each route arriving was given a unique ID (integer) that was used to offset the original coordinates of the public transportation stops by multiplying the original coordinates (x or y) by the unique ID times 3 meters. In Figure 6 the original coordinates have been offset along the y-axis into 3 new stops that equal the different routes arriving at that stop. The in-vehicle time is equal to the scheduled time for the specific route and not a mean value based on all routes or average speed. The design also has the immediate benefit that interchanges between routes can now be conducted according to the time schedule by establishing line segments between the new established stops. To reduce the number of possible interchanges, the interchange time (time between arrival and departure) was restricted to a maximum of 20 minutes. In the top example in Figure 6 all possible interchanges are shown. Restricting the interchange time only allows 1 interchange to be conducted. The arrival at 07:21 allows for an interchange to the route leaving at 07:35 and the link wait is thus 14 minutes. No other interchanges are possible.

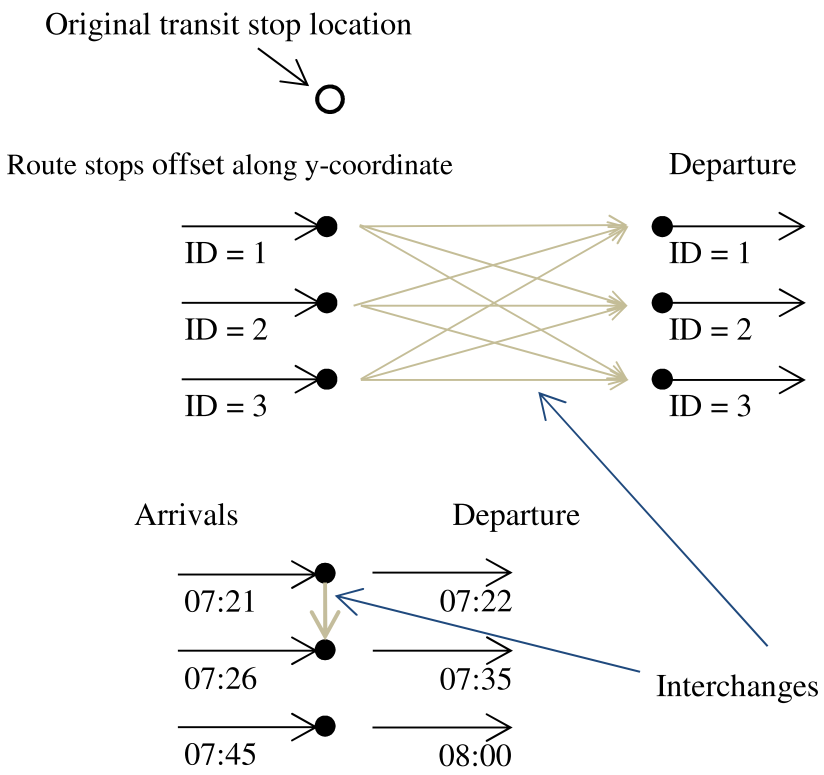

Figure 6 Split of original stop location into a number of stops equal to routes arriving or departing the stop. Possible interchanges were established according to the time table (lower part)

Transfers from one stop to another were conducted along the walk links established by the origin – destination matrices. The walk links combines two of the established unique route stops if the arrival at a stop was linked to a departure at another stop within walking distance. Only transfers of a maximum of 1 km walking distance and transfer time (time between arrival and departure) of a maximum 20 minutes were allowed. Figure 7 shows how transfers were made possible between a bus stop and a train station by using the established walk links. Walk links had been established between all transport modes as well as between stops with the same transport mode that are not connected by any route. In Figure 7, the walk between the two stops takes 6 minutes according to the distance calculated in GIS and a walking speed of 5 km/h, as illustrated by the orange arrow. In the multimodal network the link weight equals both the walk time and the wait time at the new stop to the departure according to the time schedule. When arriving at 07:14 at the train station, the weight of the walk link will therefore be 8 minutes where 6 minutes are passed walking to the bus station and 2 minutes is the wait time to the bus departure.

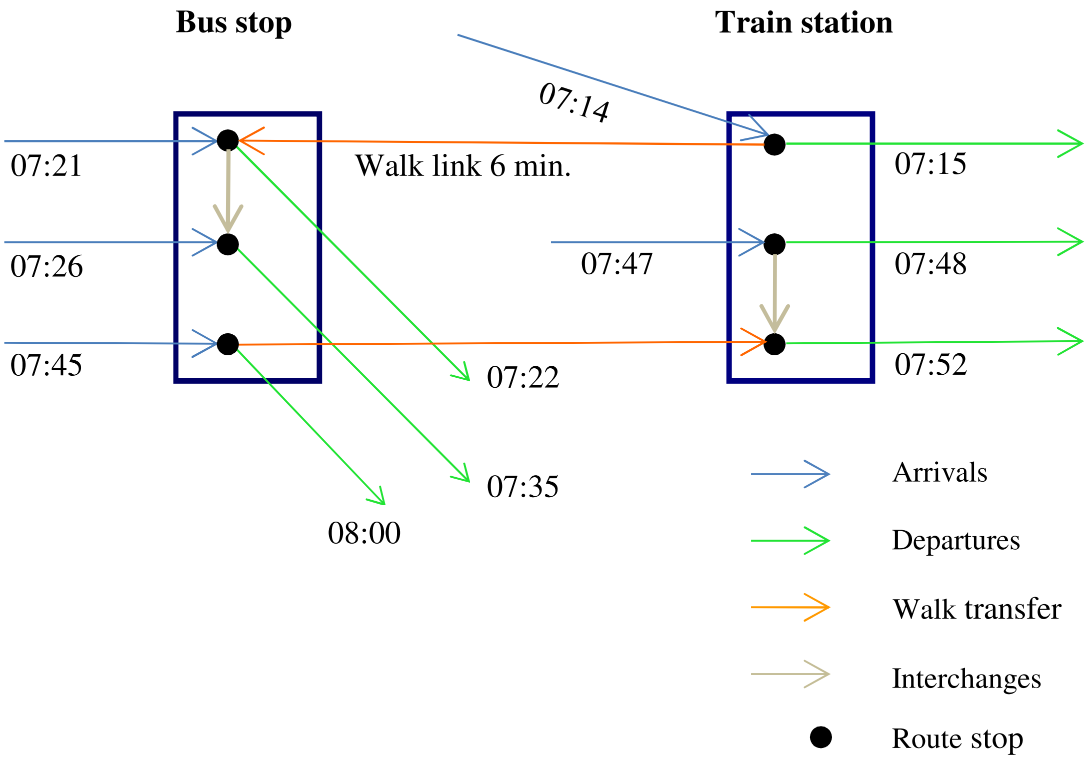

Figure 7 An illustration of unique routes arriving at their unique locations at a bus stop and a train station (blue arrows), interchanges (grey arrows), walk transfers between to stops (orange arrows) and departures (green arrows)

The access to the public transportation network was conducted along walk links from the home address to all stops reachable within 1 km walking or 3 km cycling distance. The access walk links were created in the same way as transfer walk links. The link weight equals the time it takes to walk from the home address down to a stop and the time it takes to wait for a service to depart at that stop. The maximum combined access and wait time was set to 20 minutes. The start time of the trip is 07:15 which equal the morning rush hour. The egress time was not built into the multimodal network but it results from travelling in the network. Egress time is time left within a certain time threshold (max. 12 min) to walk away from a stop. It is converted into areas calculated as walking in all directions (service areas) on the road network from the Danish Geodata Agency (see section 3.6.5).

3.5 Active commuting - outcome

The primary outcome variable investigated in papers I and III was being an active commuter (yes/no) and meeting recommended daily levels of 30 minutes' moderate-to-vigorous intensity physical activity only by active commuting (yes/no). Active commuting was self-reported by replying the question: "How many hours and minutes do you use on walking or cycling to and from work or education daily". The response was dichotomised into being an active commuter with a cut point of 4 minutes and 30 minutes' active commuting for meeting recommendations of physical activity in both papers I and III.

3.6 Objective measures of public transportation

The objective distance and density measures were calculated as the network distance from the geocoded home addresses (origins) of each respondent to the public transportation stops (destinations). The Origin – Destination matrices tool in the Network Analyst application in ArcGIS 10.1 allows calculation of the "walking" routes for a large number of respondents in the same process. The road network theme from The Danish Geodata Agency was used as network dataset. The impedance in the network was distance in meters along the road network.

3.6.1 *Distance to nearest transit stop*

For each respondent, the distance to the nearest bus stop, train station, S-train station and metro station was measured. The distances were used both as continuous and as categorised variables in paper I. The categorisation was conducted to reflect distances that people are willing to walk or bike to a public transportation stop. The categorisation of distance to the nearest bus stop reflects the distances often used in the literature (400 & 800 metres). As 76.6% of the respondents residing within 400m of a bus stop, it was decided to categorise respondents into living right next to a bus stop (0 – 200m), residing within immediate walking distance from a bus stop (201 – 400m) and residing within a long distance to a bus stop (400 - 800 m) and having a long walking distance to a bus stop (> 800 m).

The metro is only present in Copenhagen city centre and the s-train and train have local coverage hence the distances to these stops are much larger than to bus stops. The categorisation for these three transport modes was chosen to reflect residing in close or far walking distance (0–500m and 501–1000 m), in cycling distance (1001–3000 m) and far from a station (> 3000 m).

3.6.2 *Density of bus stops*

The density of bus stops was counted as number of bus stops within 1 km network distance of each of the respondents' home address. The 1 km network distance is inspired by The National Travel Survey conducted in 2006 – 2007 (122). In that survey, the mean walking distance for any trip purpose in the Capital Region of Denmark was found to be 1 km and cycling distance for any trip purpose was 3 km.

In paper I the density of stops was categorised into 4 classes based partly on the distribution of density, the stops for each respondent and having an equal number of possible stops in the categories. The categories are 0-5, 6-10, 11-15 and >15 stops.   .

3.6.3 *Access to different transport modes*

The presence of different transport modes within walking or cycling distance was used in paper I as an alternative density measure expressing the ability to access more destinations. The transport mode index (TMI) is a count of transport modes (bus, train, S-train, metro) reachable within 1 km walking or 3 km cycling (network distance) from the respondents home addresses. The index with values from 0 to 4 was defined as:

$$TMI_{walk/cycle} = Bus(0,1) + Metro(0,1) + S\text{-}Train(0,1) + Train(0,1)$$

3.6.4 *Bus service characteristics*

The service characteristics were extracted on a Tuesday during morning rush hour (07:00 – 08:00) in a normal week (week no. 9). From this time window, service characteristics were extracted for each identified nearest stop and all stops within walking distance (1 km).

The number of uniquely active bus routes at nearest bus stop was counted. The bus stop is thereby evaluated by how many different services are available during rush hour. In paper I the measure is categorised into three categories of having ≤ 1, 2, and ≥ 2 routes. Furthermore the number of uniquely active bus routes accessible within walking distance (1 km) was counted. This measure was created to get a better description of the services available in the neighbourhood as an alternative to the traditional density of stops measure. Four stops within walking distance may only be served by the same bus route in one area. In other areas four stops may be served by five different routes hence the necessity to evaluate this measure. The route density was categorised into four categories; 0-2, 3-4, 5-6, and > 6 routes.

Bus service frequency was counted as the number of departures in any direction at a given bus stop between 07:00 and 08:00 in the morning. Two measures were created; service frequency at the nearest bus stop (no distance limit) and service frequency at the "best" stop within walking distance (1 km). The best stop was set equal to the stop with the highest service frequency. If two stops within 1 km had the same service frequency, the one nearest to the respondents' home address was selected as the "best" stop. The service frequency measure at the nearest stop was subsequently categorised into 4 classes describing a bus departing between 0 and 2 times within the given hour, a departure every 10 to 20 minutes, a departure every 4 to 9 minutes, and at least a departure every 4 minutes. The service frequency at the "best" stop was also categorised into four categories describing having a departure of up to every 6 minutes, having a departure every 3 to 6 minutes, having a departure every 3 to 1½ minutes, and having a departure at least every 1½ minute.

A bus convenience measure was created combining the distance to and service frequency at the nearest stop and the distance to and service frequency at the “best” connected stop. The created 4 by 4 matrix is shown in table 1.

Table 1 Bus convenience matrix based on distance to a bus stop combined with the bus departure frequencies to form an expression of how convenient the bus services are for an individual.

	Bus frequency			
Distance to bus stop	High	Medium-high	Medium-low	Low
Close	4	4	3	2
Medium Close	4	4	3	2
Medium Far	3	3	1	1
Far	2	2	1	1

3.6.5 *Public transportation accessibility*

Individual accessibility determined in paper II and analysed in paper III was defined as the area an individual is able to cover using active transport modes e.g. walking and cycling in combination with public transportation (bus, train, S-train, and metro). The accessibility was calculated during rush hour on a Monday morning between 07:15 and 08:15. The accessibility area was defined as the area that can be covered within 30, 45 and 60 minutes’ travel time starting from the home address using active modes (walking and cycling) of transportation in combination with public transportation. The individuals’ work address was not known, so accessibility was used to express the potential for reaching other destinations by covering an area directly linked to the public transportation network. This is seen as a proxy for how attractive the public transportation network is for the commuters.

Three measures of individual accessibility by public transportation were defined; the accessibility area using services at nearest stop (distance), all stops within 1 km of walking from home address (density based) and all stops within 3 km of cycling from home address. All stops within cycling distance were chosen in addition to walking to describe accessibility in the rather large rural part of the study area. The access area was calculated as:

$$AAo = Aac + Aegr \quad (1)$$

AAo is accessibility area for a given origin o, Aac is the initial access area resulting from network distances of 1 km walking or 3 km cycling in all directions from home address. For the nearest transit stop measure, AAo equals a 1 km egress area at the first stop (in which it is located). Aegr is the sum of areas resulting from walking from all reachable stops (destinations in the multimodal network) in all directions with a distance that equals the time left when arriving at the destination.

The egress time was restricted to a maximum of 12 minutes (1 km walking) or by the three defined travel time thresholds used to express local and regional accessibility: 30, 45 and 60 minutes. It is not allowed to exit the vehicle between stops so the individual access area is the sum of the areas that can be covered walking from reachable destinations (egress). If total travel time at a stop is 24 minutes, the egress area equals walking 6 minutes in all directions from that particular stop when using the 30 minutes' travel time threshold.

The modelling was conducted in three steps (paper II). The first step was to calculate travel time from origin to destinations in all directions. The travel time to destinations was calculated by using origin – destination matrices. Accessing the public transit network at all stops within 1 or 3 km network distance creates multiple route solutions and thereby multiple travel time for the same destination. In order to calculate the highest potential accessibility area, the shortest travel time was found for each station using simple SQL querying.

The second step was to calculate the egress areas that make up the accessibility area. The egress areas were calculated as service areas based on the road network. In the third step, the individual egress areas were dissolved at individual level (unique ID) to create the individual accessibility area. Three accessibility measures were determined per individual in the study population (nearest stop, all stops within walking, and all stops within cycling distance stops) and further divided into the time thresholds of 30, 45 and 60 minutes. Only 30 and 60 minutes accessibility areas were used in paper III, where they were divided into quartiles to investigate the association with active commuting.

3.7 Individual level characteristics (confounders)

Individual socio-demographic characteristics were included as confounder in the analyses in papers I and III. The characteristics comprised age, gender, and educational level. Educational level was defined by four classes based on the highest completed education; primary or secondary school, vocational education, academy or bachelor degree, and master's or PhD degree. Educational level was used to describe the individual socio-economic position.

3.8 The neighbourhood socioeconomic environment (confounder)

Based on the assumption that individual health behaviour is affected by the area in which the individual lives, the median income level at parish level was included as a confounder in paper I and III. There are 223 parishes on the Zealand part in the region. The median income level was calculated from individual income level of all inhabitants in the study area grouped by parish code (4 digits) and was included as a continuous variable. The median income level ranged from 144,922 to 446,287 Danish kroner and the geographical distribution based on parishes is shown in Figure 8.

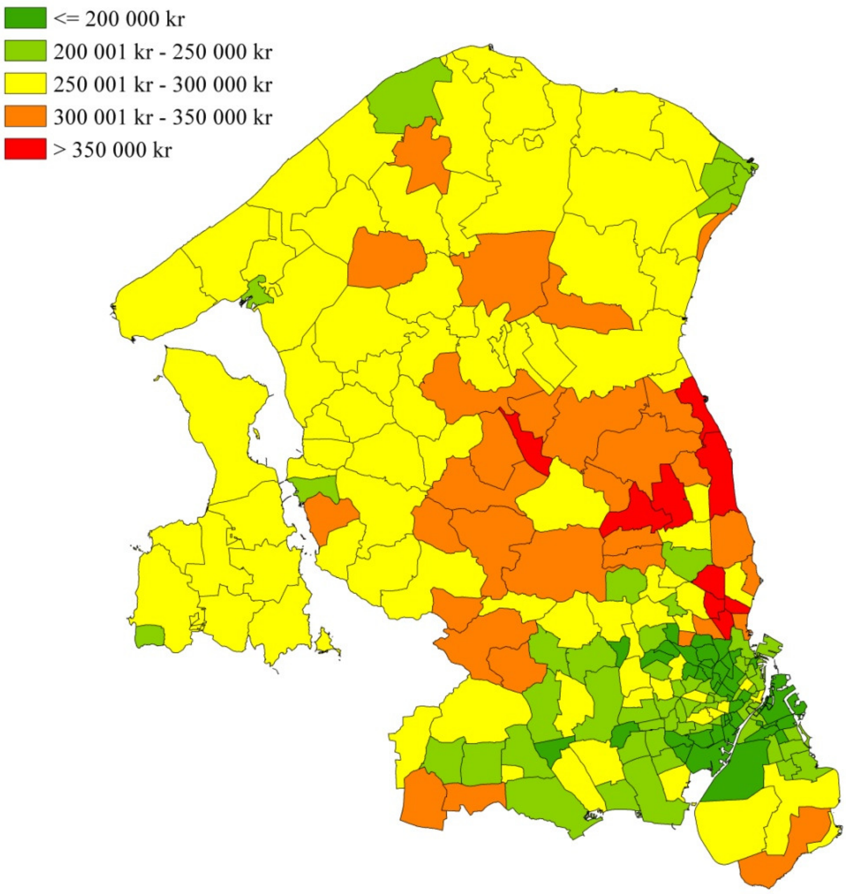

Figure 8 Population median income calculated from register-based population aged 16+ by parishes.

3.9 The neighbourhood population density

In papers I and III the neighbourhood population density based on parishes was included as a confounder. Population density is a proxy for urbanity. As described in section 3.1 the Capital Region of Denmark consists of rural, suburban, and urban areas. By including population density as a confounder, it is possible to account for the differences in access to public transit and other opportunities and also different norms and lifestyles. The population density is expressed in the number of inhabitants per km^2 and is included as a continuous variable. The population density ranged between 35.7 and 33,703.8 inhabitants per km^2 and the geographical distribution is shown in Figure 9.

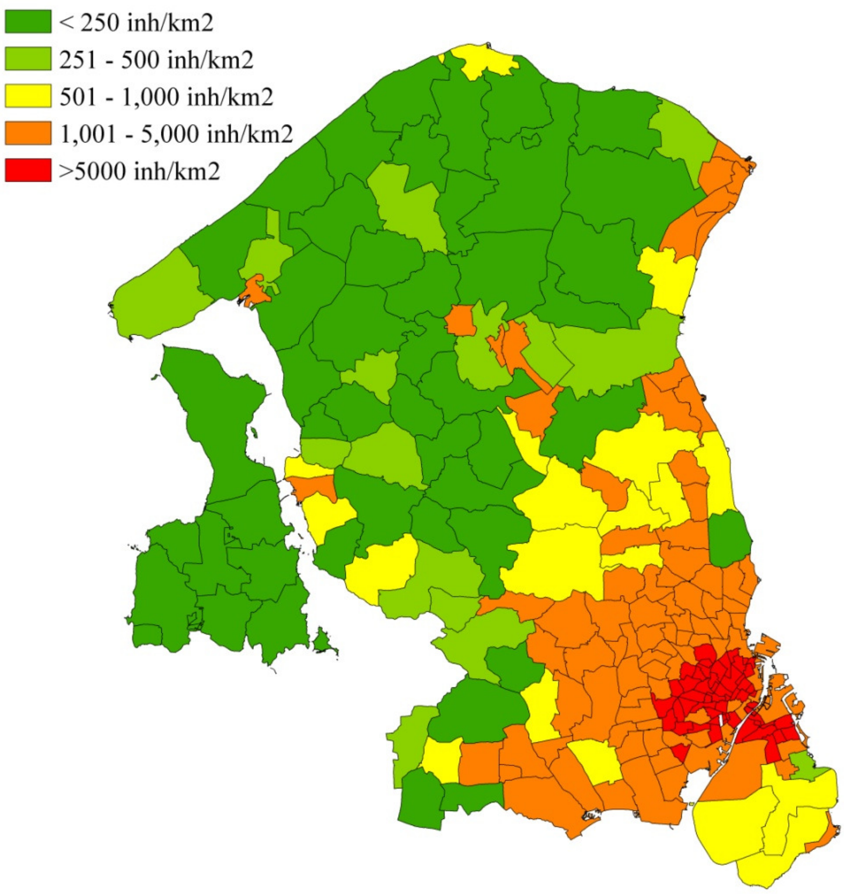

Figure 9 Population density calculated by summing the total register-based population living in each parish in the Capital Region of Denmark.

3.10 The neighbourhood street connectivity

The neighbourhood street connectivity was included in papers I and III as a confounder. Connectivity accounts for differences in how easy it is to move around on roads and walking paths in the various neighbourhoods in the region. Some of the urban areas have a clear gridded and highly accessible infrastructure whereas some of the rural areas only have few possible routes when walking from A to B. In this study, street connectivity was defined by the gamma index (74) calculated at parish level:

$$\gamma = \frac{1}{3(n-2)}, \text{ n equals intersections}$$

The values range between 0 and 1, having 1 representing the maximum number of links present. A value of 0.60 can be expressed as a network that is 60 % connected. The gamma index in this study ranged between 0.37 and 0.71. The values were grouped in quintiles. The geographical distribution of the gamma index quintiles is shown in Figure 10.

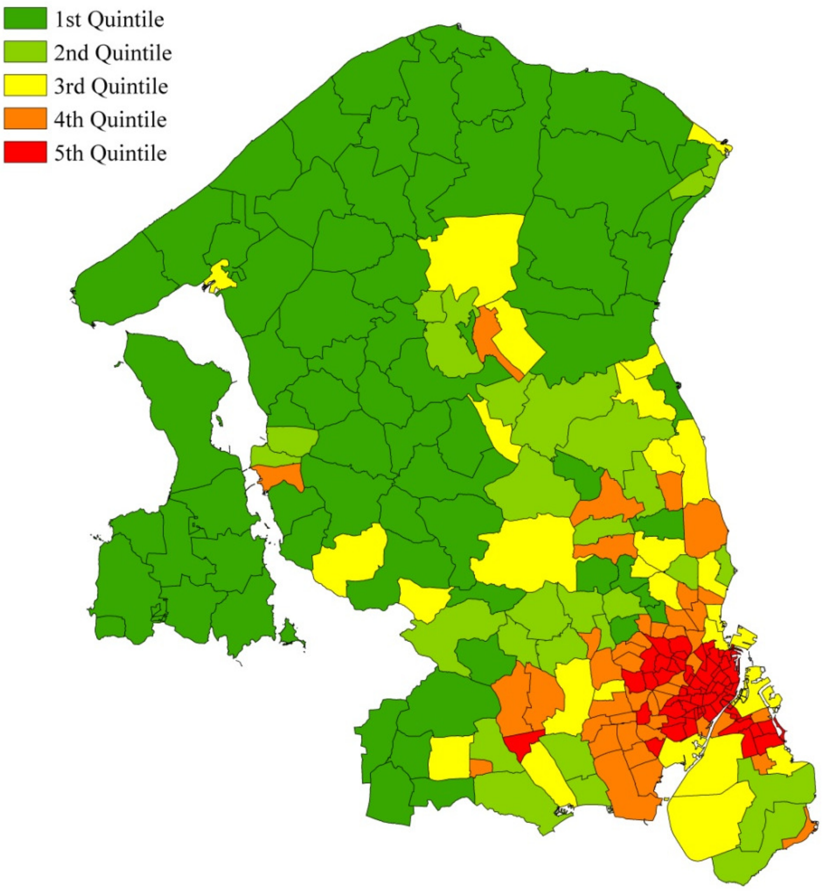

Figure 10 The street connectivity gamma index expressed as quintiles based on parishes.

3.11 Statistical analyses

The statistical analyses in Papers I and III were based on the same setup. In order to examine whether access to and accessibility of public transportation were associated with individual active commuting and assuming that the social and physical environment of the neighbourhood influence individual health behaviour, we used multilevel regression models (123-128). Data were fitted to the multilevel framework by organizing the data in a hierarchical structure having individuals at level 1 and neighbourhoods (parishes) at level 2. This approach follows the socio-ecological perspective on health assuming that respondents living in the same neighbourhood are more alike than those from different neighbourhoods.

3.11.1 *Paper I analyses*

The association between access to public transportation and 1) being active, and 2) meeting recommended levels of physical activity by active commuting, was analysed using multilevel logistic regression by the GLIMMIX procedure in SAS version 9.3 (SAS Institute, Inc., Cary, North Carolina). A two level model was fitted with individuals (level 1, n= 28,928) nested within parishes (level 2, n = 223). A conceptual diagram of the model is shown in Figure 11.

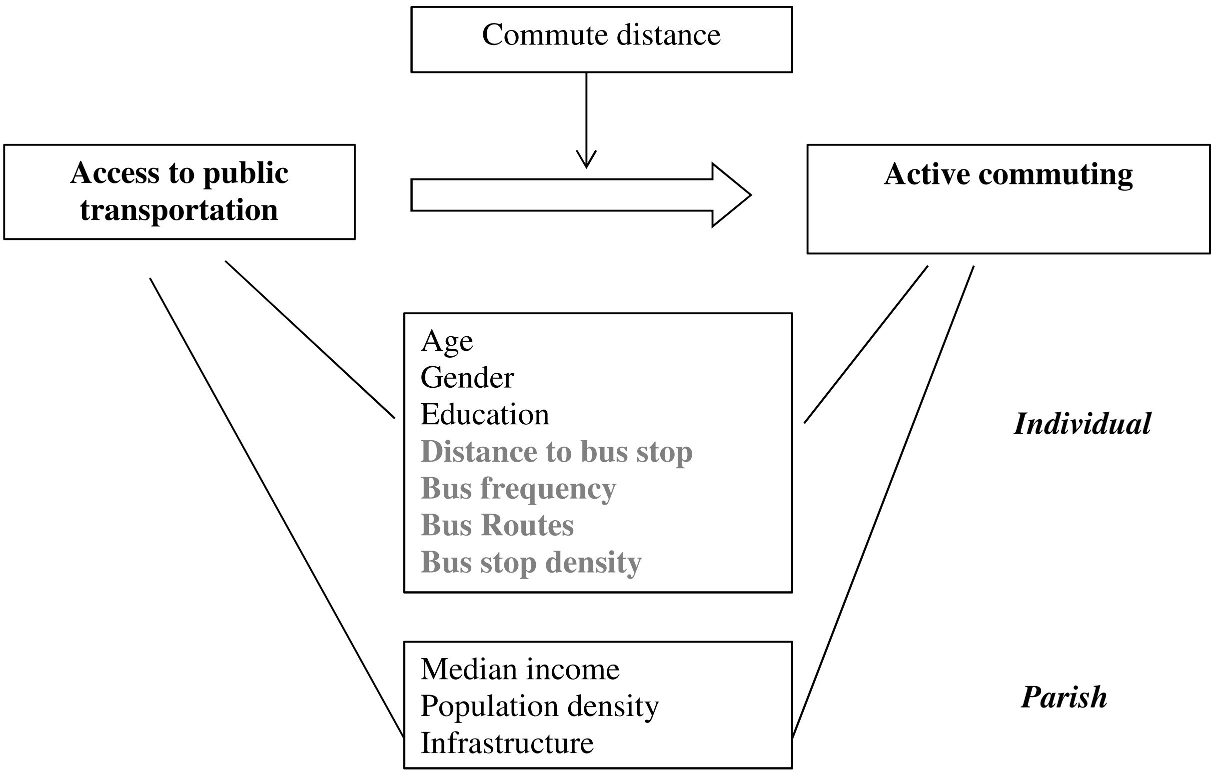

Figure 11 A conceptual diagram of the statistical approach in paper I. The grey coloured individual confounders are not included in all models, see section 3.11.1.

Prior to running the multilevel analysis a pair-wise correlation matrix was constructed to identify variables that were highly correlated. Highly correlated values were defined as having a Pearson's correlation coefficient of > 0.55 (12;129). The results were used to evaluate the risk of multicollinearity in the models.

Two "empty" models were estimated to detect if there was a contextual dimension to 1) being an active commuter and to 2) meeting daily recommended levels of physical activity by active commuting. The contextual dimension was estimated by calculating the Intra Class Coefficient (ICC) (128). ICC ranges between 0 and 100 % and represents the proportion of the unexplained variance of the dependent variable (level 1) that can be explained by the neighbourhoods (level 2). A 3-step modeling strategy was used and ICC was calculated for each model. First the primary explanatory variable was included (unadjusted model). In this paper 15 explanatory variables were used leading to 15 model runs.

Secondly the individual level covariates were included to examine whether the between-parish variance was attributable to a compositional effect. Individual age, gender and education were included in all 15 models. In addition to the individual socio-demographic variables, bus frequency and number of routes at nearest bus stop were included in the models with the explanatory variables distance to nearest bus, density of bus stops and unique routes within 1 km. The distance to nearest bus stop was included in the models with the explanatory variables distance to train, metro and S-train. The distance to nearest bus stop and bus frequency at nearest stop was included in the model with the explanatory variable unique bus routes at nearest stop. The distance to nearest bus stop and unique bus routes at nearest stop were included in the model with the explanatory variable bus frequency at the nearest stop. Unique bus routes at nearest stop were included in the model with the explanatory variable bus convenience at nearest stop. The density of stops within 1 km was included in the models with explanatory variables bus frequency at "best stop" and bus convenience at "best stop".

Thirdly the parish-level covariates (median income, population density, street connectivity) were included to explore if the remaining between-parish variance could be explained by contextual factors. The results from the analysis were presented as odds ratios (OR) with 95 % confidence intervals (CI), which estimate the odds of 1) being an active commuter and 2) meeting daily recommended levels of moderate-to-vigorous intensity physical activity. Furthermore to see if the association differed among subgroups, it was examined if there was a significant interaction with distance to work expressed by living ≤ 5 km, 5 to 10 km, 10 – 20 km and ≥ 20 km from work or study, age and gender.

3.11.2 *Paper III analyses*

The association between public transportation accessibility and 1) being an active commuter, and 2) meeting recommended levels of physical activity by active commuting was analysed using multilevel logistic regression by the GLIMMIX procedure in SAS version 9.3 (SAS Institute, Inc., Cary, North Carolina). A two level model was fitted with individuals (level 1, n= 28,928) nested within parishes (level 2, n = 223). A conceptual diagram of the model is shown in Figure 12.

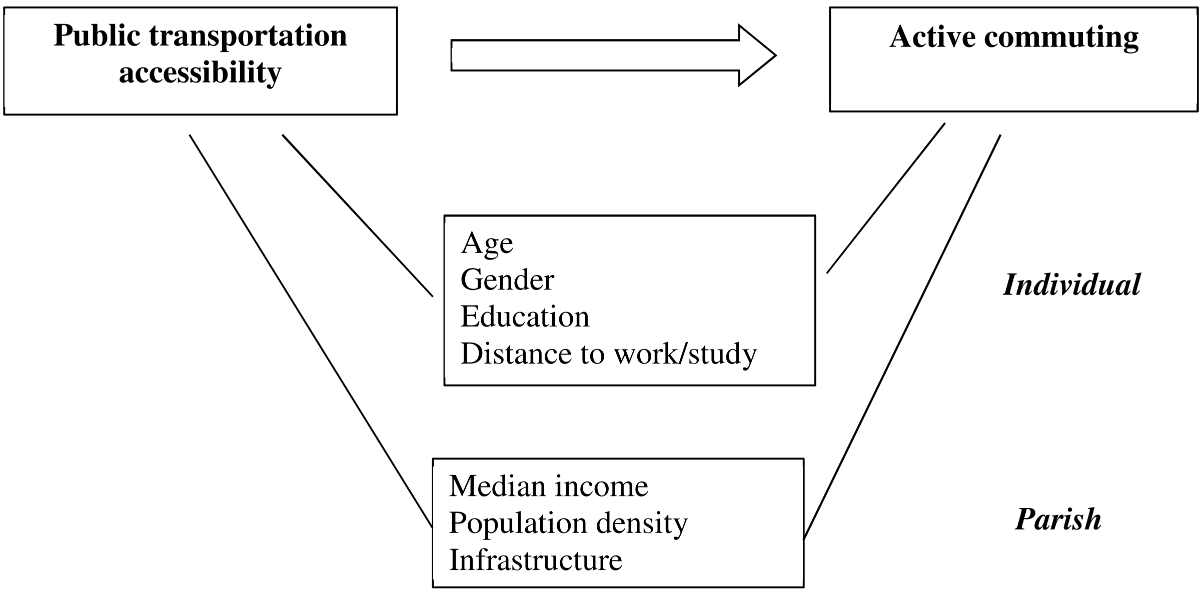

Figure 12 A conceptual diagram of the statistical approach in paper III

First the primary variable was included. This paper has 6 explanatory variables leading to 6 model runs. Secondly the individual level covariates (age, gender, education) were included to examine whether the between-parish variance was attributable to a compositional effect. Thirdly the parish-level covariates (median income, population density, connectivity) were included to explore if the remaining between-parish variance could be explained by contextual factors. The results from the analyses were presented as odds ratios (OR) with 95 % confidence intervals, which estimate the odds of being an active commuter. Furthermore to see if the association differed among subgroups, it was examined if there was a significant interaction with distance to work expressed by four groups that represent distances with high but decreasing amount of active commuting with distance 0-5 km, 5-10 km and 10-20 km and > 20 km. in addtion it was examined if there was a significant interaction with age expressed by three subgroups indicating different stages in life; 16-29 years, 30-45 years and 46-64 years. And lastly it was examined if there was a significant interaction with gender.

4. Results

4.1 Study population characteristics

The socio-demographic characteristics of the study population are shown in Table 2. The study sample consisted of 56.3% women, the mean age was 41 years (SD= 13.1) and 16.3% had a university degree while 26.8 had a vocational education.

Table 2 The distribution of age, gender, education and commute distance by subgroups of active commuters (> 4min/day) (yes/no) and meeting recommendations of physical activity (yes/no).

	Total	**Active commuter (> 4min/day)**		**Meeting recommended levels of physical activity (≥ 30min/day)**	
		Yes	**No**	**Yes**	**No**
	N (%)	N (%)	N (%)	N (%)	N (%)
Total population	28,928 (100)	21,094 (72.9)	7834 (27.1)	14,629 (50.6)	14,299 (49.4)
Age[a]	40.9 (13.1)	39.7 (13.5)	44.3 (11.2)	39.3 (13.7)	42.6 (12.2)
Age groups (6 missing)					
16 - 29 years	6538 (22.6)	5724 (87.5)	814 (12.5)	4245 (64.9)	2293 (35.1)
30 - 45 years	10,782 (37.3)	7507 (69.6)	3275 (30.4)	5056 (46.9)	5726 (53.1)
46 - 64 years	11,604 (40.1)	7860 (67.7)	3744 (32.3)	5327 (45.9)	6277 (54.1)
Gender (6 missing)					
Male	12,624 (43.6)	8518 (67.5)	4106 (32.5)	5709 (45.2)	6915 (54.8)
Female	16,300 (56.3)	12,573 (77.1)	3727 (22.9)	8919 (54.7)	7381 (45.3)
Education (438 missing)					
Primary or secondary school	8150 (28.2)	6434 (78.9)	1716 (21.1)	4608 (56.5)	3542 (43.5)
Vocational education	7742 (26.8)	4920 (63.5)	2822 (36.5)	3273 (42.3)	4469 (57.7)
Academy or bachelor degree	7898 (27.3)	5822 (73.7)	2076 (26.3)	3992 (50.5)	3906 (49.5)
Master or PhD degree	4723 (16.3)	3593 (76.1)	1130 (23.9)	2501 (53.0)	2222 (47.0)
Commute distance					
0 - 5 km	9237 (31.9)	7957 (86.1)	1280 (13.9)	5731 (62.0)	3506 (38.0)
5 - 10 km	6676 (23.1)	5117 (76.6)	1559 (23.4)	3995 (59.8)	2681 (40.2)
10 - 20 km	6516 (22.5)	4265 (65.5)	2251 (34.5)	2730 (41.9)	3786 (58.1)
> 20 km	6499 (22.5)	3755 (57.8)	2744 (42.2)	2173 (33.4)	4326 (66.6)

[a] Age is expressed by mean and standard deviation

A total of 72.9% of the respondents reported more than 4 minutes of active commuting per day and 50.6% reported 30 minutes or more active commuting per day. More respondents between 16 and 29 years of age were active commuters and met the recommended levels of physical activity compared to the older respondents. More women were active commuters than men. Respondents with a vocational education had a lower proportion of active commuters and meeting recommendations of physical activity than the other education groups. The proportion of active commuters as well as respondents meeting recommended levels of physical activity were highest for those with commute distances ≤ 5 km and the proportion of active commuters decreased with increasing commute distance.

The mean distance to work was 14.6 km (SD = 15.9), see Table 3. Active commuters reported shorter commute distances (12.7 km) than non-active commuters (19.6 km). Mean individual distance to the nearest bus stop was 300 meters, whereas the mean distance to train and S-train varied from approximately 4 km to as far as 13.3 km to the nearest metro stop. Active commuters had on average shorter mean distances to nearest train, s-train and metro stop than non-active commuters.

Table 3 Distance to the different public transportation modes in the population by subgroups of active commuters (> 4min/day) (yes/no) and meeting recommendations of physical activity (yes/no).

	Total	**Active commuting (> 4min/day)**		**Meeting recommended levels of physical activity (≥ 30min/day)**	
		Yes	**No**	**Yes**	**No**
Km	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Distance to work or education	14.6 (15.9)	12.7 (14.8)	19.6 (17.6)	11.8 (14.0)	17.1 (17.2)
Distance to bus stop	0.3 (0.2)	0.3 (0.2)	0.4 (0.3)	0.3 (0.2)	0.3 (0.3)
Distance to train station	4.2 (3.5)	4.0 (3.3)	4.8 (4.0)	3.8 (3.1)	4.6 (3.8)
Distance to S-train station	4.1 (5.8)	3.7 (5.4)	5.3 (6.6)	3.3 (5.0)	5.0 (6.4)
Distance to metro stop	13.3 (14.2)	11.6 (13.3)	17.9 (15.5)	10.1 (12.4)	16.6 (15.1)

4.2 Access to public transportation and active commuting (paper I)

4.2.1 *The association between distance to public transportation stops and active commuting*

Table 4 shows the association between distance to public transportation and the odds of being an active commuter. After adjusting for potential confounders, greater distance to public transportation was associated with lower odds of being an active commuter. Residing > 400 meters from a bus stop was associated with significantly lower odds of being an active commuter compared to residing within 400 meters, and residing > 800 meters from a bus stop was associated with significantly lower odds of being an active commuter compared to residing within 800 meters. For trains, S-trains and metro there was a similar dose-response trend, as greater distance to a station was associated with lower odds of being an active commuter. For trains and S-trains, there was only a significant difference in the association for those residing > 3 kilometres from a train or S-train station compared to residing within 500 metres. The ICC in the two empty models showed a noticeable significant between neighbourhood variation of 13.6% in being an active commuter and 12.7 % in meeting recommendations of physical activity. ICC in the unadjusted models varied from 5.3 to 12.7 % and was significantly reduced to between 1.6 and 2.1% in the fully adjusted model.

Table 4 Crude and adjusted associations (OR) between objective distance measures to public transportation and being an active commuter. Between-neighbourhood variation is expressed by the Intra-class correlation coefficient (ICC).

	Model 1: Crude OR (CI)	**Model 2: Model 1 + Individual co-variates** OR (CI)[b]	**Model 3: Model 2 + Neighbourhood co-variates** OR (CI)[c]
Distance to bus stop (km)	**0.71 (0.63 - 0.80)**	**0.70 (0.62 - 0.79)**	**0.76 (0.67 - 0.85)**
P-value[a]	*<0.0001*	*<0.0001*	*<0.0001*
ICC	*12.6*	*9.2*	*2.1*
Distance to bus stop (m)			
Close (≤ 200)	1.00	1.00	1.00
Moderate Close (201 - 400)	1.00 (0.94 - 1.07)	1.00 (0.93 - 1.07)	1.02 (0.95 - 1.09)
Moderate Far(401 - 800)	**0.88 (0.82 - 0.96)**	**0.89 (0.82 - 0.96)**	**0.92 (0.85 - 1.00)**
Far (>800)	**0.68 (0.58 - 0.80)**	**0.68 (0.58 - 0.80)**	**0.73 (0.62 - 0.86)**
P-value[a]	*<0.0001*	*<0.0001*	*<0.0001*
ICC	*12.8*	*9.4*	*2.1*
Distance to train station (km)	**0.93 (0.91 - 0.94)**	**0.94 (0.92 - 0.95)**	**0.97 (0.96 - 0.98)**
P-value[a]	*<0.0001*	*<0.0001*	*<0.0001*
ICC	*11.3*	*8.9*	*2.1*
Distance to train station (m)			
Close (0 - 500)	1.00	1.00	1.00
Medium Close (501 - 1000)	0.92 (0.76 - 1.12)	0.95 (0.78 - 1.17)	0.97 (0.79 - 1.18)
Medium Far (1001 - 3000)	0.84 (0.69 - 1.02)	0.87 (0.71 - 1.05)	0.86 (0.71 - 1.03)
Far (>3000)	**0.65 (0.52 - 0.80)**	**0.69 (0.56 - 0.85)**	**0.75 (0.62 - 0.91)**
P-value[a]	*<0.0001*	*<0.0001*	*0.0002*
ICC	*12.8*	*9.9*	*2.1*
Distance to S-train station (m)			
Close (0 - 500)	1.00	1.00	1.00
Medium Close (501 - 1000)	0.99 (0.87 - 1.12)	1.03 (0.90 - 1.17)	1.03 (0.90 - 1.17)
Medium Far (1001 - 3000)	**0.79 (0.70 - 0.90)**	**0.84 (0.74 - 0.96)**	0.89 (0.78 - 1.00)
Far (>3000)	**0.53 (0.44 - 0.62)**	**0.55 (0.47 - 0.65)**	**0.81 (0.69 - 0.94)**
P-value[a]	*<0.0001*	*<0.0001*	*0.0002*
ICC	*9.6*	*7.0*	*2.0*
Distance to metro stop (m)			
Close (0 - 500)	1.00	1.00	1.00
Medium Close (501 - 1000)	0.83 (0.66 - 1.04)	0.84 (0.67 - 1.06)	0.86 (0.68 - 1.08)
Medium Far (1001 - 3000)	**0.66 (0.52 - 0.84)**	**0.72 (0.56 - 0.91)**	**0.78 (0.63 - 0.98)**
Far (>3000)	**0.27 (0.21 - 0.35)**	**0.32 (0.25 - 0.40)**	**0.56 (0.45 - 0.71)**
P-value[a]	*<0.0001*	*<0.0001*	*<.0.0001*
ICC	*5.2*	*3.9*	*1.6*

[a]P-value from type III test of the association.
[b]Bus distance adjusted for age, gender, education, bus routes and bus frequency. Train, S-train and metro adjusted for age, gender, education and distance to bus.
[c]Adjusted for population density, median income, street connectivity.

4.2.2 *The association between public transportation density measures and being an active commuter*

Table 5 shows the association between the different density measures and the odds of being an active commuter. In the unadjusted models both density of bus stops, bus routes within 1 km and the number of transport modes within walking or cycling distance were all positively associated with being an active commuter. The associations were attenuated when adjusted for individual and contextual confounders, but remained significant. An increase in the density of bus stops, bus routes or access to more transport modes was associated with significantly higher odds of being an active commuter. The ICC in the unadjusted models ranged from 5.0 to 10.7 and was significantly reduced to 1.7 – 1.9% in the fully adjusted models.

Table 5 Crude and adjusted associations (OR) between objective density measures of public transportation and being an active commuter. Between-neighbourhood variation is expressed by the Intra-class correlation coefficient (ICC).

	Model 1: Crude OR (CI)	**Model 2: Model 1 + Individual co-variates** OR (CI)[b]	**Model 3: Model 2 + Neighbourhood co-variates** OR (CI)[c]
Density of bus stops			
Low (0 - 5)	1.00	1.00	1.00
Medium low (6 - 10)	**1.29 (1.20 - 1.39)**	**1.33 (1.24 - 1.43)**	**1.25 (1.16 - 1.34)**
Medium high (11 - 15)	**1.56 (1.42 - 1.71)**	**1.58 (1.44 - 1.74)**	**1.32 (1.20 - 1.45)**
High (>15)	**2.42 (2.12 - 2.76)**	**2.43 (2.14 - 2.77)**	**1.52 (1.32 - 1.75)**
P-value[a]	*<.0.0001*	*<.0.0001*	*<.0.0001*
ICC	*6.4*	*3.9*	*1.8*
Bus routes at stops within 1 km			
Low (0-2)	1.00	1.00	1.00
Medium low (3-4)	**1.17 (1.08 - 1.26)**	**1.22 (1.13 - 1.31)**	**1.14 (1.05 - 1.23)**
Medium High(5-6)	**1.49 (1.34 - 1.65)**	**1.54 (1.39 - 1.71)**	**1.27 (1.14 - 1.41)**
High (>6)	**1.75 (1.56 - 1.96)**	**1.86 (1.66 - 2.08)**	**1.31 (1.16 - 1.48)**
P-value[a]	*<.0.0001*	*<.0.0001*	*<.0.0001*
ICC	*8.1*	*4.8*	*1.8*
Transport mode index (TMI) 1 km			
0[d]	**0.67 (0.53 - 0.83)**	**0.64 (0.51 - 0.8)**	**0.67 (0.54 - 0.85)**
1	1.00	1.00	1.00
2	**1.29 (1.20 - 1.4)**	**1.29 (1.20 - 1.4)**	**1.19 (1.11 - 1.29)**
3	**1.53 (1.30 - 1.79)**	**1.51 (1.28 - 1.77)**	**1.35 (1.16 - 1.56)**
P-value[a]	*<.0.0001*	*<.0.0001*	*<.0.0001*
ICC	*10.7*	*8.7*	*1.9*
Transport mode index (TMI) 3 km			
1[d]	1.00	1.00	1.00
2	**1.35 (1.21 - 1.51)**	**1.35 (1.21 - 1.51)**	**1.19 (1.07 - 1.33)**
3	**1.85 (1.61 - 2.12)**	**1.85 (1.62 - 2.12)**	**1.42 (1.24 - 1.62)**
4	**4.30 (3.57 - 5.18)**	**4.00 (3.35 - 4.79)**	**1.87 (1.53 - 2.28)**
P-value[a]	*<.0.0001*	*<.0.0001*	*<.0.0001*
ICC	*4.9*	*4.0*	*1.7*

[a]P-value from type III test of the association.
[b]Unique bus routes within 1 km adjusted for density of bus stops, age, gender and education. Density of bus stops adjusted for age, gender, education, bus routes at nearest stop and bus frequency at nearest stop. TMI 1 and 3 km adjusted for age, gender and education.
[c]Adjusted for population density, median income and street connectivity.
[d]The number represents number of transport modes within walking(1 km) and cycling distance (3 km).

4.2.3 *The association between bus service measures and being an active commuter*

Table 6 shows the association between bus service level and being an active commuter. In the adjusted models, the associations between bus routes and frequency at the nearest stop and being an active commuter were insignificant. A higher bus service frequency at the “best” stop was associated with significantly higher odds of being an active commuter except for the medium-low frequency. No significant association was found between bus convenience at the "best" stop and being an active commuter.

Table 6 Crude and adjusted associations (OR) between objective measures of public transportation services and being an active commuter. Between-neighbourhood variation is expressed by the Intra-class correlation coefficient (ICC).

	Model 1: Crude OR (CI)	**Model 2: Model 1 + Individual co-variates** OR (CI)[b]	**Model 3: Model 2 + Neighbourhood co-variates** OR (CI)[c]
Bus routes at nearest stop			
Low (≤ 1)	1.00	1.00	1.00
Medium (2)	1.00 (0.93 - 1.07)	0.96 (0.88 - 1.03)	0.98 (0.91 - 1.05)
High (>2)	1.03 (0.95 - 1.12)	0.91 (0.82 - 1.01)	0.97 (0.88 - 1.07)
P-value[a]	*0.7272*	*0.2027*	*0.7919*
ICC	*13.7*	*9.1*	*2.0*
Frequency of bus service at nearest stop			
Low (0-2)	1.00	1.00	1.00
Medium-low (3 - 6)	**0.90 (0.83 - 0.98)**	**0.90 (0.83 - 0.99)**	**0**.92 (0.85 - 1.01)
Medium-high (7 - 15)	1.02 (0.93 - 1.12)	1.04 (0.94 - 1.15)	1.00 (0.91 - 1.11)
High (> 15)	1.07 (0.96 - 1.18)	1.08 (0.96 - 1.23)	0.96 (0.84 - 1.08)
P-value[a]	*0.0008*	*0.0012*	*0.1148*
ICC	*12.6*	*9.2*	*2.1*
Frequency of bus services at "best stop"			
Low (<= 10)	1.00	1.00	1.00
Medium low (11 - 20)	**1.21 (1.10 - 1.32)**	**1.13 (1.04 - 1.24)**	1.09 (0.99 - 1.19)
Medium high (21 - 40)	**1.43 (1.30 - 1.57)**	**1.28 (1.17 - 1.41)**	**1.15 (1.04 - 1.26)**
High (> 40)	**1.99 (1.77 - 2.24)**	**1.58 (1.40 - 1.79)**	**1.26 (1.11 - 1.43)**
P-value[a]	*<.0.0001*	*<.0.0001*	*<.0.0001*
ICC	*7.2*	*2.6*	*1.6*
Bus convenience at nearest stop			
Low (1)	1.00	1.00	1.00
Medium-low (2)	**1.17 (1.06 - 1.29)**	**1.16 (1.04 - 1.29)**	**1.12 (1.01 - 1.25)**
Medium-high (3)	1.07 (0.98 - 1.16)	1.07 (0.98 - 1.17)	1.06 (0.97 - 1.15)
High (4)	**1.30 (1.19 - 1.43)**	**1.30 (1.18 - 1.44)**	**1.19 (1.08 - 1.32)**
P-value[a]	*<.0.0001*	*<.0.0001*	*0.0016*
ICC	*11.7*	*9.6*	*2.1*
Bus convenience at "best" stop			
Low (1)	1.00	1.00	1.00
Medium-low (2)	1.05 (0.98 - 1.13)	1.04 (0.93 - 1.11)	1.00 (0.93 - 1.08)
Medium-high (3)	**1.19 (1.10 - 1.29)**	**1.11 (1.02 - 1.20)**	1.06 (0.97 - 1.14)
High (4)	**1.28 (1.12 - 1.47)**	1.15 (1.00 - 1.31)	1.11 (0.97 - 1.26)
P-value[a]	*<.0.0001*	*0.0667*	*0.3100*
ICC	*12.3*	*3.8*	*2.0*

[a]P-value from type III test of the association.
[b]Bus routes at nearest stop adjusted for distance to nearest bus stop, bus frequency at nearest stop, age, gender and education. Bus frequency at nearest bus stop adjusted for distance to nearest bus stop, bus routes at nearest stop, age, gender, education. Bus convenience at nearest stop adjusted for bus routes at nearest stop, age, gender and education. Bus frequency at "best" stop and Bus convenience at "best" stop adjusted for density of bus stops within 1 km, age, gender and education.
[c]Adjusted for population density, median income and street connectivity.

The ICC in the unadjusted models ranged from 7.2 to 13.6 and was significantly reduced to 1.6 – 2.2% in the fully adjusted models.

4.2.4 *Distance to work, age and gender in relation to active commuting*

Significant interactions were observed between all public transportation access measures (except categorised distance to train) and commute distance (p-values ranged from <0.0001 to 0.0439), see appendix 2. For those with commute distances ≤ 10 km the associations showed significantly lower odds of being an active commuter with increasing distance to public transportation and significantly higher odds of being an active commuter with increasing density of stops, more available routes and transport modes. For respondents with commute distances > 10 km the associations became insignificant to a large extent.

For women, distance to public transportation was associated with lower odds of being an active commuter and higher density is associated with higher odds of being an active commuter. For men, the associations were insignificant to a large extent and with no clear trend. Only transport modes accessible within 3 km showed a trend towards increasing number of transport modes being associated with significantly higher odds of being an active commuter.

For the age group between 30 and 45 the associations found in the adjusted models remained. These associations remained significant to a large extent but less pronounced in the age group between 46 and 64. For the age group between 16 and 29, the associations were insignificant to a large extent and with no clear or an inverse trend.

4.2.5 *Association with meeting recommended levels of physical activity by active commuting*

The adjusted models showed the same but less pronounced associations between the objective measures of public transportation and ≥ 30 minutes of active commuting per day. The distance to nearest bus stop and train station was significantly inversely associated with meeting recommendations of physical activity by active commuting. A higher density of stops and increasing number of transport modes within 3 km cycling was associated with significantly higher odds of ≥ 30 minutes of active commuting per day. The number of bus routes and transport modes within 1 km walking distance showed a positive trend with ≥ 30 minutes of active commuting per day, but having a high number of bus routes and at least 3 transport modes were not significantly associated with higher odds of meeting recommendations compared to a low number of bus routes and no transport modes available. The service measures showed no significant association between services at the nearest stop and ≥ 30 minutes of active commuting per day but a positive association was found between service frequency at "best" stop and ≥ 30 minutes of active commuting per day.

The subgroup analysis showed a strong positive association between all density measures and ≥ 30 minutes of active commuting per day for those with commute distances of 5 to 10 km. In those having ≤ 5 km commute distance, there was a positive trend between density measures and ≥ 30 minutes of active commuting per day. For commute distances of > 10 km the associations became insignificant. The interaction analyses with age and gender showed the same associations as described in section 4.2.4.

In addition specific detailed results on interactions and meeting recommendations of physical activity are presented in Appendix 2.

4.3 Building a multimodal network to determine public transportation accessibility area (Paper II)

The multimodal network constituted six major transport modes e.g. bus, train, S-train, metro, ferry and walking. All the public transport modes and their time schedules (arrivals and departures) were obtained from the travel planner and a multimodal public transportation network with travel time as travel cost was built. Walk links between stops were calculated in a GIS, using road network distances and integrated in the network. The resulting network model is shown in Figure 13 without walk links. The network model handled all travel time components in accordance with the travel planner schedules and was easily integrated into a GIS network model.

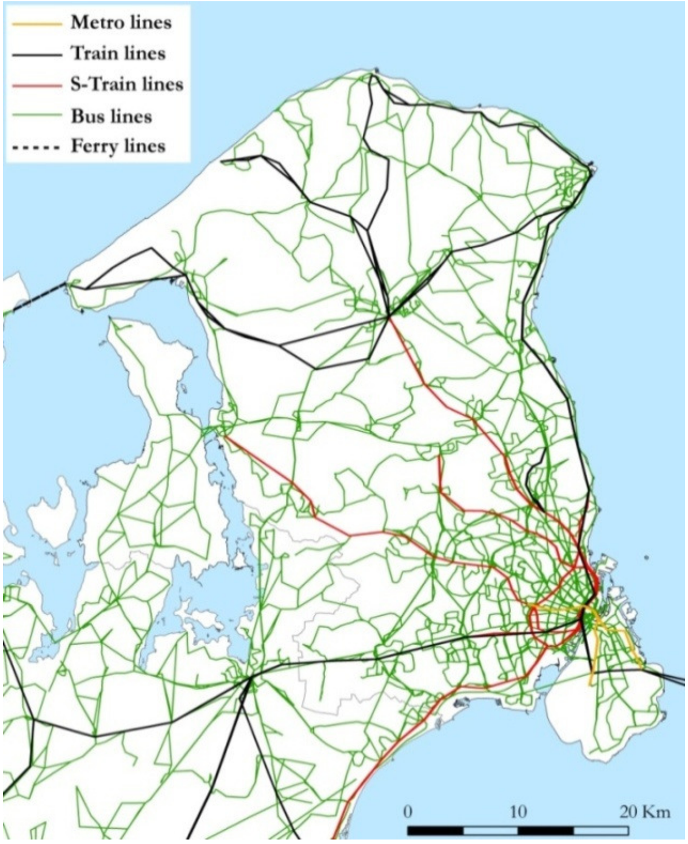

Figure 13 The constructed multimodal network consisting of 5 transport modes. Walk links between stops are not included in this Figure. Connections between stops are constructed as straight lines with a weight corresponding to scheduled travel time.

The accessibility area was calculated based on entering the public transportation network at the nearest stop, all stops within 1 km walking distance or all stops within 3 km cycling distance and travel times thresholds of 30, 45 and 60 minutes. The accessibility areas resulting from entering all stops within walking distance when living in Copenhagen inner-city (A) and in the rural area (B) of the Capital Region of Denmark are shown in Figure 14.

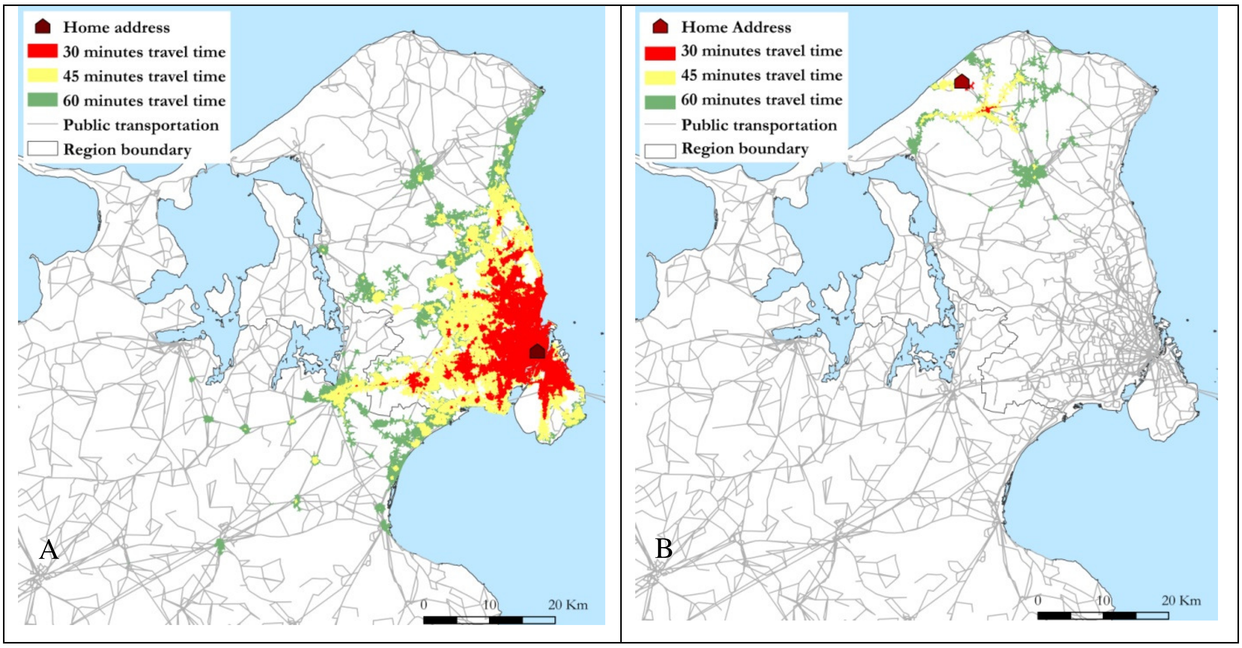

Figure 14 Accessibility areas based on all stops within walking distance from home address (1 km). The shown accessibility areas results from travelling 30, 45 and 60 minutes by public transportation from home address in a metropolitan (A) and in a rural setting (B)

The mean individual public transportation accessibility area based on all three access models (nearest stop, 1 km walking and 3 km cycling) and the time travel threshold subdivided by Copenhagen inner-city, suburban and smaller city areas, and rural areas, are shown in Table 7.

Table 7 Mean (and range) accessibility area sizes based on individual public transportation of participants living in Copenhagen inner-city area, suburban and city areas and in the rural area (overview of the different zones in Figure 2).

Travel time	**Copenhagen inner-city area** Mean km^2 (range km^2)	**Suburban and city areas** Mean km^2 (range km^2)	**Rural area** Mean km^2 (range km^2)
Nearest stop			
30 min	64.8 (0 - 209.2)	23.7 (0 - 181.1)	6.5 (0 - 65.3)
45 min	250.8 (0 - 500.2)	117.4 (0 - 449.4)	27.0 (0 - 332.6)
60 min	424.6 (0 - 695.0)	251.4 (0 - 647.6)	77.3 (0 - 518.3)
Stops within 1 km walking distance			
30 min	95.4 (0 - 235.8)	37.4 (0 - 191.7)	8.9 (0 - 68.6)
45 min	334.7 (0 - 510.8)	167.6 (0 - 454.7)	36.3 (0 - 332.7)
60 min	538.9 (0 - 695.1)	332.2 (0 - 650.8)	99.4 (0 - 518.4)
Stops within 3 km cycling distance			
30 min	143.1 (16.7 - 235.9)	73.2 (0 - 192.8)	18.6 (0 - 100.3)
45 min	407.6 (122.1 - 510.9)	246.5 (0 - 473.0)	58.0 (0 - 353.5)
60 min	607.6 (324.7 – 713.3)	427.4 (0 - 671.0)	139.1 (0 - 522.0)

The accessibility areas are smallest in the rural zone and become larger in the suburban zone and in Copenhagen inner-city. The 30 minutes´ travel time result is much smaller accessibility areas than 45 and 60 minutes travelling.

4.4 Public transportation accessibility and active commuting (paper III)

The association between accessibility and being an active commuter is shown in Table 8. After adjusting for confounders, the accessibility area (30 and 60 minutes) resulting from accessing the nearest stop did not show a significant association with being an active commuter. The accessibility areas resulting from accessing all stops within walking distance were significantly positively associated with being an active commuter. An increase in accessibility area was associated with significantly higher odds of being an active commuter. The same dose-response relationship was observed in the association between the accessibility area resulting from accessing all stops within cycling distance and being an active commuter although there was no difference in odds of being an active commuter in the medium-low and the medium-high accessibility groups. The ICC in the unadjusted models ranged from 3.7 to 11.5 and was significantly reduced to 1.2 – 1.4 % in the fully adjusted models.

Table 8 Crude and adjusted associations (OR) between individual public transportation accessibility (using the nearest stop, all stops within walking distance or all stops within 3 km cycling distance) and being an active commuter. Between-neighbourhood variation is expressed by the Intra-class correlation coefficient (ICC).

	Model 1: Crude OR (CI)	**Model 2: Model 1 + Individual co-variates** OR (CI)[b]	**Model 3: Model 2 + Neighbourhood co-variates** OR (CI)[c]
Nearest stop 30 minutes Acc.			
Low	1.00	1.00	1.00
Medium low	**0.92 (0.85 - 1.00)**	**0.91 (0.84 - 0.99)**	0.93 (0.86 - 1.01)
Medium high	1.05 (0.96 - 1.14)	1.07 (0.98 - 1.17)	1.03 (0.94 - 1.12)
High	**1.21 (1.10 - 1.34)**	**1.25 (1.13 - 1.38)**	1.05 (0.95 - 1.17)
P-value[a]	<.0001	<.0001	0.0607
ICC	11.6	4.7	1.4
Nearest stop 60 minutes Acc.			
Low	1.00	1.00	1.00
Medium low	1.00 (0.92 - 1.09)	1.02 (0.94 - 1.11)	1.04 (0.96 - 1.13)
Medium high	1.07 (0.98 - 1.17)	**1.11 (1.01 - 1.21)**	1.03 (0.95 - 1.13)
High	**1.27 (1.14 - 1.41)**	**1.34 (1.20 - 1.48)**	1.07 (0.96 - 1.19)
P-value[a]	0.0002	<.0001	0.6310
ICC	11.4	4.6	1.4
Stops within walking distance 30 minutes Acc. (1 km)			
Low	1.00	1.00	1.00
Medium low	**1.26 (1.16 - 1.37)**	**1.27 (1.17 - 1.37)**	**1.17 (1.08 - 1.27)**
Medium high	**1.70 (1.54 - 1.87)**	**1.65 (1.50 - 1.81)**	**1.33 (1.21 - 1.47)**
High	**2.13 (1.90 - 2.39)**	**2.03 (1.83 - 2.26)**	**1.37 (1.21 - 1.55)**
P-value[a]	<0.0001	<0.0001	<0.0001
ICC	6.2	1.8	1.2
Stops within walking distance 60 minutes Acc. (1 km)			
Low	1.00	1.00	1.00
Medium low	**1.41 (1.28 - 1.54)**	**1.32 (1.21 - 1.44)**	**1.17 (1.07 - 1.28)**
Medium high	**1.90 (1.71 - 2.11)**	**1.69 (1.53 - 1.86)**	**1.34 (1.21 - 1.49)**
High	**2.73 (2.41 - 3.10)**	**2.28 (2.03 - 2.55)**	**1.44 (1.26 - 1.66)**
P-value[a]	<0.0001	<0.0001	<0.0001
ICC	4.8	2.1	1.3
Stops within cycling distance 30 minutes Acc. (3 km)			
Low	1.00	1.00	1.00
Medium low	**1.62 (1.45 - 1.81)**	**1.44 (1.29 - 1.60)**	**1.21 (1.09 - 1.35)**
Medium high	**2.20 (1.95 - 2.49)**	**1.70 (1.52 - 1.90)**	**1.20 (1.06 - 1.36)**
High	**3.36 (2.94 - 3.84)**	**2.44 (2.16 - 2.76)**	**1.44 (1.24 - 1.67)**
P-value[a]	<0.0001	<0.0001	<0.0001
ICC	4.2	1.9	1.3
Stops within cycling distance 60 minutes Acc. (3 km)			
Low	1.00	1.00	1.00
Medium low	**1.61 (1.44 - 1.80)**	**1.42 (1.28 - 1.58)**	**1.20 (1.07 - 1.33)**
Medium high	**1.98 (1.76 - 2.23)**	**1.58 (1.42 - 1.76)**	**1.19 (1.05 - 1.34)**
High	**3.60 (3.15 - 4.13)**	**2.56 (2.27 - 2.90)**	**1.45 (1.24 - 1.71)**
P-value[a]	<0.0001	<0.0001	<0.0001
ICC	3.8	2.0	1.3

[a]P-value from type III test of the association.
[b]Adjusted for age, gender, education, commute distance.
[c]Adjusted for population density, median income and street connectivity

4.4.1 *Distance to work, age and gender in relation to active commuting*

The interaction between the public transportation accessibility area and categorised commute distance was significant for all measures of accessibility (p-values <0.0001). For those living within 10 kilometers of the work or study place, all accessibility areas showed a trend that a larger accessibility area was associated with being an active commuter. For the accessibility areas resulting from 1 km walking or 3 km cycling, an increase in accessibility area was associated with significantly higher odds of being an active commuter. For commuters having between 10 and 20 km commute distance, an increase in the accessibility area (1 km walking and 3 km cycling) was associated with significantly higher odds of being an active commuter in the medium-low quartile of accessibility compared to low accessibility. Although the other quartiles showed significantly higher odds of being active compared to the low accessibility quartile, the odds were not significantly higher than for the medium-low quartile. Having more than 20 km commute distance, the associations between accessibility area and being an active commuter became insignificant. Having high accessibility based on the nearest stop and 3km cycling (60 minutes) resulted in lower odds of being an active commuter compared to having low accessibility.

The subgroup analysis with age showed that for the age category 16 to 29 years, the association between accessibility (1 km walking and 3 km cycling) and being an active commuter was insignificant. For the respondents in the other two age groups, 30 – 45 and 46 – 64 years, the accessibility was positively associated with being an active commuter. The association was strongest among the 30 to 45-year-old.

For women there was a significant positive association between accessibility area based on all stops within walking and cycling distance and being an active commuter. Furthermore women having high accessibility based on services at the nearest stop (30 and 60 minutes) had significantly higher odds of being an active commuter compared to the reference group (low). For men the associations were insignificant.

4.4.2 *Association with meeting recommended levels of physical activity*

Positive associations were found between the density accessibility areas and meeting recommendations on physical activity although less pronounced compared to the associations with being an active commuter, see supplement results in Appendix 3. There was a significant interaction between all accessibility areas and distance to work or study. Positive significant associations were found between all density measures and meeting recommendations of physical activity for participants with commute distance of ≤ 10 km. The associations were strongest for those having between 5 and 10 km commute distance. For participants having between 10 and 20 km commute distance, a medium-low or medium-high accessibility based on 1 km walking or 3 km cycling was associated with significantly higher odds of meeting recommendations of physical activity compared to having low public transportation accessibility. High accessibility was not significantly associated with higher odds of meeting recommendations of physical activity compared to low accessibility. For those having more than 20 km commute distance, accessibility area was not associated with meeting recommended levels of physical activity.

The interaction with age was significant for all measures. The subgroup analysis showed that for the age category 16 to 29 years, the association between accessibility and meeting recommendations of physical activity was insignificant and even significantly inversely associated for medium high and high accessibility based on all stops within walking distance. For the respondents in the other two age groups, the accessibility (30 and 60 minutes) was positively associated with meeting recommendations of physical activity.

For women there was a significantly positive association between accessibility area based on all stops within walking and cycling distance and meeting recommendations of physical activity. No significant associations were found for women between accessibility based on services at the nearest stop (30 and 60 minutes) and meeting recommendations of physical activity. For men the associations were less pronounced, although suggesting that higher accessibility based on walking and cycling was positively associated with meeting recommendations of physical activity.

In addition, results from the association between public transportation accessibility area and meeting recommended levels of physical activity as well as all subgroup analysis for active commuting are attached in Appendix 3.

5. Discussion

The overall aim of this thesis was to explore the associations between the objective measures of access to public transportation and active commuting as well as to investigate the association between individual public transportation accessibility and active commuting. Furthermore it was assessed whether commute distance, age and gender modified the association between access to public transportation and active commuting as well as if commuting distance, age and gender modified the association between the accessibility and active commuting. New and known objective measures of access to public transportation were tested in order to contribute knowledge on which features of public transportation facilitates active commuting. In order to calculate the individual public transportation accessibility, a method for integrating time schedules into a multimodal network model for use in standard GIS was developed. The main findings from the three papers, upon which this thesis is built, are described and discussed in relation to other studies below.

5.1 Measures of access to public transportation and association to active commuting (paper I)

The distance to public transportation is important for using active transport modes when commuting. The associations found are supported by a number of studies showing that proximity to public transportation stops is significantly associated with utilitarian walking (15), greater distance to railway stations is associated with significantly lower odds of walking for transportation (18) and significantly lower odds of cycling and public transport use (12). In this study, greater distance to a bus stop was associated with significantly lower odds of being an active commuter. The association was more pronounced here than for the other public transport modes. Due to the large study area many respondents have very long distances to the train, S-train and metro stations. This clearly attenuates the associations for these three transport modes. Locally, the three transport modes are very important for commuting by public transportation in the region with direct and fast services to the main city centres.

The association between the distance measures and meeting recommendations of physical activity was less pronounced than the associations of being an active commuter, but remained significant. A few other studies have investigated distance measures in relation to meeting recommendations of physical activity. McConville et al. (18) found the same significant association but they compared meeting the recommended levels to “non-walkers” and therefore found much lower odds for distance to bus and train. Lachapelle and Frank (25) found that transit users living within 450 to 1000 meters of a transit stop were significantly more likely to be moderate walkers (<30 minutes walking per day) but not with meeting the recommendations of physical activity (≥ 30minutes walking per day). On the other hand

Hino et al. (29) did not find an association between distance to nearest bus or BRT tube station and meeting recommended levels of physical activity.

Although density measures are often based on different distance thresholds reflecting different contexts and commute patterns, studies consistently find density of bus stops or public transportation stops to be positively associated with walking for transport (16;18;29) and meeting the recommendations of physical activity (16;18). In the present study, all four density measures were significantly positively associated with being an active commuter. Although the number of stops within an area reflects how well-connected the public transportation is, the alternative measures created in this study, unique routes and accessible transport modes were intended to better describe the diversity of services in the neighbourhood. The positive associations found may not only reflect a higher use of public transportation in areas of high density, but also better connected street networks (see the gamma index, Figure 10) that allow more direct travelling and the presence of cycle lanes that facilitate active commuting. The positive associations attenuated with respect to meeting recommendations of physical activity, but remained significant for the density of stops and transport modes accessible within cycling distance. There was a trend that higher density and more transport modes were associated with higher odds of meeting the recommendations of physical activity.

The public transportation services such as the routes active or the frequency of departures are perceived as important characteristics that facilitate the use of public transportation (20). Surprisingly, no significant associations were found between the routes or the service frequency at the nearest stop and being an active commuter. The number of routes at nearest stop is very low and therefore the variation may be too small in the measure to obtain statistical difference. The frequency measure shows much more variation but the association becomes insignificant when adjusting for the neighbourhood level confounders. The association with the bus frequency has only been investigated in relation to active commuting in few other studies (12;21;26). Dalton et al. (12) found that medium (tertiles) and low bus frequencies were significantly associated with lower odds of using public transportation compared to having a high frequency. Kamada et al. (21) did not find a significant association but their sample size was small and therefore had very low statistical power. The "best" stop measure in this study represents the most attractive bus stop within walking distance which on the other hand showed significantly higher odds of being an active commuter and meeting the recommendations of physical activity. It is likely that commuters are willing to walk to a stop with more frequent services if the nearest stop provides poor service or does not provide the service that can bring the commuters to their work or study place.

In the present study, having a high frequency and a short distance to the nearest stop are associated with significantly higher odds of being active compared to having longer distances and low frequency. This was not significant for the "best" stop convenience measure or in association to meeting the recommendations of physical activity. Kamada et al. (21) did not find a significant association between their convenience measure and active commuting, but their results showed the same positive trend that higher convenience was associated with higher odds of active commuting. It is highly questionable, however, whether the two studies are comparable as Kamada et al. (21) investigated women living in a rural setting in Unnan City, Japan, with a generally low public transportation service level.

5.1.1 *Distance to work, age and gender in relation to active commuting*

The distance to work has been identified as one of the most important predictors of travel mode choice (11;12;130). When the commuting distance is > 10 km the number of commuters who cycle all the way to work decreases markedly and car-based commuting becomes dominant (11). This is also evident from the results of this study. A positive attitude towards using public transportation to commute has been observed to decrease with the commuting distance which partly explains why car-based commuting dominates at longer commute distances (130). This may explain why the associations become insignificant for respondents having commuting distances > 10 km. For those residing within 10 km from work or study, the associations between the objective measures and active commuting are more pronounced for those having ≤ 5 km commuting distance. This relationship changes when looking at meeting the recommendations of physical activity where those having a commuting distance between 5 and 10 km show more pronounced associations.

Women's commute travel choices seem to be more influenced by access to public transportation than men. The associations found in the full model remain significant and in the same magnitude for women, but for men these associations become insignificant. Men's travel choice may be more influenced by car ownership. However, data on car ownership were not available in the present study.

The 16 to 29 year olds are to a large extent walking or cycling in combination with using public transportation which may explain the non-significant associations between the access measures and being an active commuter. The travel choice in the 30 to 45 year old group seems to be much more influenced by access to public transportation and a higher access and service level result in higher odds of being an active commuter. The associations become less pronounced for the 46 to 64 year olds. This may be the result of more car-based commuting and possibly also caused by less cycling or walking due to functional decline with age.

5.2 Building a multimodal network and determine public transportation accessibility (paper II)

Whereas the access to public transportation has been widely studied in relation to active commuting, the overall public transportation accessibility has not been assessed. One of the big challenges of modeling accessibility using a standard GIS is how to handle the temporal component that restricts the possible travel links when using public transportation. In the literature, the modelling of the different parts of travel time varies both because of the lack of data, simplifications to overcome the changing temporal component or full or partial integration of travel schedules (87;92;98;106-111). The present study proposed a method for constructing a multimodal network of public transportation from a travel planner enabling the integration of the temporal component in a door-to-door approach including all parts of a trip from an individual home address to all reachable areas within a given travel time threshold. The main approach was to split the original public transportation stop into a number of stops equal to the number of arrivals and departures at a stop. The split was conducted by off-setting the original stop coordinates by a unique number assigned to each route times multiplied by a specified number of meters.

Splitting transit stops into a stop per service enabled interchanges, transfers between services as well as handling the wait time in accordance with the time-table. The design thereby overcomes some of the challenges of using a standard GIS, such as using half the headway time as wait and transfer time. Thus, the model is suitable for modelling the individual public transportation accessibility integrating travel planner data. Another benefit of the simple two-dimensional approach is that it enables other GIS software than ArcGIS to perform the O-D matrix calculations.

In the proposed model, the access to public transportation followed the distances used in paper I. The accessibility was thus calculated using the services at nearest stop, all stops within walking distance (1 km) and all stops within cycling distance (3 km). The time it takes to walk to a stop was calculated from distance to stop with a walking speed of 5 km/h. Other studies of public transportation accessibility do not describe specifically how the access distance is taken into account, although they describe that the access time is included in the travel time (92;103;106-110). Benenson et al. (87) used a 300 meter crow-fly (Euclidean) distance as maximum access distance. Given the importance of the distance to a stop in relation to active commuting, it would be very valuable to know if a maximum distance is used and if it is the network distance or Euclidean distance. In line with the density approach in the proposed model, O'Sullivan et al. (107), Lei and Church (98) and Salonen and Toivonen (92) included accessing other stops than the nearest stop in order to capture the timeliest connections. The large differences between the accessibility area size resulting from entering only at the nearest stop, and including all stops within 1 kilometre walking (Table 7), highlight how sensitive the accessibility measure is to include access to other than the nearest stop.

Average speed between stops based on the route start departure and route end arrival time has been used by some authors as the in-vehicle time (106;107). As noted by O'Sullivan et al. (107) this simplification will likely underestimate the bus speed in the suburban (and rural) area and overestimate the bus speed in the city centre. In addition, wait time has been calculated as half the headway time (103;107;109) or a fixed time (108;111). Salonen and Toivonen (92) found that using half the headway as a surrogate for transfer related wait time, clearly underestimates the travellers' ability to optimize their journey. Integrating the time schedule into the network provides more true in-vehicle and wait time. In the same way, the time schedule can be used to restrict which interchanges and transfers that are allowed in accordance with the scheduled arrivals and departures.

The transfer walks were integrated by calculating walking distances between stops (≤ 1 km) and integrating arrivals and departures from the time schedules. These were not present in the original dataset but transfer between modes is often essential to a flexible transportation. Benenson et al. (87), O'Sullivan et al. (107) and Gent & Symonds (109) also integrate transfer walk links but in some of the earlier studies they are ignored (106). In addition, Lei and Church (98) identify the shortest elapsed time for transfers based on the time schedule, but how this is implemented in their model is not fully described. Finally, Salonen and Toivonen (92) used the travel planner to model travel time. Interchanges and transfers were handled by the travel planner and relied on the walking speed and distances agreed upon by transport authorities. When using the API method, the challenges of building temporal enabled multimodal networks in GIS may be overcome, but researchers do not have a lot of options to change the parameters of the travel planner such as walking speed, the size of walk links etc.

The egress areas ultimately make up the individual public transportation accessibility area. As with the access time, egress time was limited to 12 minutes walking or time left within a given travel time threshold. Benenson et al. (87) used a similar approach to model egress time, but they used 500 meter Euclidean distance at stops. Other studies do not explicitly describe if the egress time is limited by time or distance (92;98;103;106-109;111).

The most common outputs from the accessibility studies are the catchment areas, isochrones maps or service areas. The individual public transportation accessibility area found by travelling in the multimodal network is a service area. Looking at the accessibility, it increases as expected when using all stops within 1 km walking distance and 3 km cycling distance as opposed to services at the nearest stop. More timely connections, other routes and other transport modes are reachable by walking beyond the nearest stop. This is important to take into account in studies of individual public transportation accessibility. It is also evident from the accessibility areas that to those living in the inner-city of Copenhagen public transportation provides high accessibility while the rural areas are much poorer covered.

5.3 Public transportation accessibility area and association to active commuting (paper III)

In paper III, the individual public transportation accessibility area was used to express the potential for reaching other destinations by covering an area directly linked to the public transportation network. The findings from the individual public transportation accessibility and its association to active commuting suggest that the individual public transportation accessibility based on density measures is associated both with being an active commuter as well as with meeting the recommendation of physical activity.

In the adjusted model individual public transportation using the nearest stop and being an active commuter showed a non-significant association and similarly when looking at meeting the recommendation of physical activity. It is surprising that the accessibility areas from the nearest stop are not associated with being an active commuter. From the study of access to public transportation (paper I) we saw a similar tendency that frequency and routes at nearest stop were not associated with active commuting. It should be noted that the accessibility measure in this paper is not restricted to bus stops but includes all types of transport modes. One explanation for the lack of association may be that the services at the nearest stop do not express the "real" accessibility well enough. Another explanation may be due to the way the accessibility is modelled. The nearest stop measure is quite sensitive to services leaving between the time a participant enters the stop until the last allowed departure time at 07:35. This can result in accessibility areas of 0 km^2 although services may leave at 07:36 and thereby lower the variance of the measure.

The fact that neighbouring stops a bit further away from the nearest stop may provide much better services is one of the main reasons why this study does not solely focus on the nearest stop. When including other stops, it is possible to account for more timely connections that expand the accessibility area. The positive association found between the individual public transportation accessibility based on stops within 1 km walking or 3 km cycling and active commuting as well as meeting the recommended levels of physical activity reflects the findings from access to public transportation studies showing that density is associated with active commuting (12;16;18;23;29). High accessibility reflects a public transportation network that is efficient in bringing individuals to other places and opportunities and is thus conductive of being an active commuter. Frank et al. (23) investigated energy expenditure in association to active transportation. They found that transit accessibility, described as the ability to access all of a region's five activity centers by walking to transit, were positively associated with energy expenditure by walking. However, it is not mentioned specifically how accessibility was calculated in the study.

The interaction with the commuting distance is consistent with findings from other studies (11;12;130). Residing within 10 km commuting distance and in areas of high accessibility is associated with being an active commuter and meeting the recommendations of physical activity. The metropolitan area and city centres have high accessibility, high density of jobs and a supportive infrastructure that promotes walking or cycling and the use of public transportation. As commute distances gets longer, car-based commuting is more prevalent and attenuates the associations. A high proportion of the respondents between 16 and 29 live close to their work or study and walk or cycle all the way. This weakens the effect of public transportation (the association is insignificant) although other studies find that this age group is the most inclined to use public transportation to travel (46;81). For the other age groups, the positive associations found reflect that using active commute modes becomes more attractive if the potential for reaching other destinations is high.

The results suggest that men's active commute patterns are less influenced by public transportation than women which may be caused by more car-based commuting. Living in areas of high accessibility is not associated with active commuting in men whereas women show a clear dose-response relationship between accessibility and the odds of being an active commuter.

5.4 Methodological considerations

The studies presented have some strengths and limitations that need to be considered.

5.4.1 *Cross-sectional design and study population*

The study population used in this thesis consists of participants from the Danish National Health Survey 2010 that is a cross-sectional survey. One of the challenges with a cross-sectional design is that it is not possible to draw conclusions on causal relationships. The results provided are a snapshot of dynamic associations. Whether it is the presence of public transportation that causes people to be active or if active commuters choose to live next to public transportation cannot be identified from this study. More longitudinal studies are warranted to test if the associations persist over time. The Danish National Health Survey has been conducted in 2013 and a new survey is planned in 2017. Combining data from these surveys can provide a basis for studying the temporal trends in the associations between the built environment and active commuting.

The high proportion of respondents reporting active commuting in this study (72.9 %) is substantially higher than those reported in the other studies in Appendix 1. It is therefore unknown whether the results may be generalizable to other countries or cities where active commuting is not as common. The observed associations are quite similar to the other studies in Appendix 1, which indicates that the findings may be comparable.

5.4.2 *Non-response and self-report bias*

The health survey had a response rate of 52.3%. The implication of this response rate was tested in a non-response analysis. The analysis showed that the response rate was highest among women, middle-aged individuals and individuals of higher socio-economic position and lowest among men, young and elderly individuals and individuals of lower socio-economic position. Accordingly a number of statistic weights have been calculated by Statistics Denmark to adjust for the non-response on municipality level. The weights have not been applied to the individual data in this study so the results are not generalizable to the whole population in The Capital Region of Denmark.

The thesis relies on self-reported data that can be subject to bias. Known self-report bias is misinterpretation of the question leading to participants failing to respond or give erroneous answers. Lack of introspective ability may lead to incorrect responses. The design of the questionnaire is built on validated scales and screening tools in order to enhance validity (116).

Commuting is routine based and very often at the same time of day (every day), bias in the self-reported active commuting responses is therefore likely to be more valid than for behaviours that occur less frequently. Commuters are often well aware of the distance or time it takes to go to work and if there are faster or slower commute modes. However, social desirability bias may lead to over reporting of physical activity(131).

5.4.3 *Data sources*

The health survey is one of the largest population based surveys in the world. The combination of the health survey with individual register based data and high accuracy geographical data, all extracted so that they cover the same time period, create a unique base for studying the association between the built environment and active commuting.

5.4.4 *The outcome variable – active commuting*

Active commuting was reported as “How many hours and minutes do you spend on walking or cycling to and from work or education daily?”. When studying the associations between access to (and accessibility by) public transportation, it is not possible to know whether active commuting is a result of walking only, cycling only or in combination with using public transportation. It is therefore not possible to conclude if better access to public transportation is associated with commuting by public transportation, only that it is associated to any form of active commuting. This would be valuable information to include in future research to get a better understanding of which features of the built environment that facilitate the different domains of active commuting. The Danish National Health Survey 2013 has included transport mode choice so future studies can elaborate more on the associations.

5.4.5 *The multilevel approach*

The multilevel model approach was chosen following the theoretical basis of the socio-ecological models that state that the physical environment, social environment and personal-level attributes may influence individual health behaviour. Estimates of the ICC showed a clear amount of variation between the neighbourhoods on the outcome variable. The neighbourhood effect was accounted for in the 3-step model and significant reduction in the variation among neighbourhoods was observed. The ICC in the fully adjusted models ranged from 0.9 to 2.2 %. The multilevel design accounted thus both for the individual and contextual confounders.

Adjusting for individual education in combination with employment and neighbourhood SES met some of the limitations regarding self-selection. Education and employment status influence where people prefer or are able to live and also their health behaviour (132).

The design and measured weights for non-response in the health survey were, as mentioned in section 5.4.2., not taken into account in the multilevel analyses. This was decided for a number of reasons. First of all the difference between including and not including the weights in regression analysis gave no significant difference in the estimates. This may be due to the fact that this study analyses individuals and the weights are based on the municipality population. Secondly the GLIMMIX procedure in SAS 9.3 is not able to include weights into a survey based multilevel analysis. This should be included in the new version 9.4. On that basis, the survey design was ignored.

5.4.6 *Neighbourhood size*

To adjust for neighbourhood covariates, neighbourhoods were defined by parishes. Parishes are old administrative units of varying size following largely the population density. This results in large units in rural areas and smaller units in the city. Geographically grouped data are always sensitive to the modifiable areal unit problem (133;134). Aggregation of data into different sizes of geographical units may lead to different results in the association studies due to differences in heterogeneity (135). Parishes were evaluated to be representative for neighbourhoods in this study, given that they were only used to adjust for neighbourhood effects and the results from the multilevel analyses support this approach. By adjusting for neighbourhood variables in the analyses, the limitations of not including residential self-selection are to some extent met in combination with individual SES (education and employment).

5.4.7 *Walking and cycling distances*

All distances were calculated similarly in paper I, II and III using network distances from geo-coded home addresses to public transportation stops. The threshold distances of 1 km walking and 3 km cycling were chosen to reflect realistic distances that commuters are willing to walk or cycle to a public transportation stop. This is supported by the findings of the National Travel Survey conducted in 2006 – 2007 (122). Furthermore distances were based on network distances only allowing walking or cycling on roads and biking/walking paths contained in the road network dataset, which is superior to using Euclidean distances.

5.4.8 *Objective measures of access to public transportation*

One of the strengths of using objective measures of built environment is that respondent bias is eliminated. In addition, objective measures are relevant to urban planners and policy makers for designing sustainable solutions in meeting the future challenges of a growing urban population. The new introduced measures including the "best" stop, bus routes within 1 km walking distance and access to different transport modes expand earlier research to get a better understanding of which correlates facilitate active commuting. However, future research will benefit from including personal attitudes towards using different transport modes as well as including perceptions of the build environment. Omitting the attitudinal variables might bias the results found.

Due to the large study area, parameters such as road safety and presence of bike lanes and sidewalks were not integrated into the distance measures, but they obviously have an effect on the choice of transport mode (13;14).

5.4.9 *The multimodal network*

The 2D model approach used to build the multimodal network model enable full control on programming which connections that can be conducted in accordance with the time schedule. A limitation to the model is that it creates a large number of nodes and links thereby making process time potentially long, when calculating service areas. By isolating arrival and departures during rush hour, the performance was high when computing all reachable stops. A 3D approach could be an alternative to the used model. A 3D model uses 3D topology so that different arrivals are places on top of each other on the same geographical location but having different height (z) coordinate equal to arrive time. This can be constructed in ArcGIS (ESRI) but the 2D approach was chosen since the method was sought to be software independent.

5.4.10 *The accessibility measure*

The accessibility area in papers II and III do not include restrictions on number of transfers that can be conducted although more stops/transfers promote car-based commuting (20;136). The time restrictions of 20 minutes on both initial access + wait time and walk transfers and wait time were chosen so that a maximum walking distance of 12 minutes would result in a maximum wait time of 8 minutes. This is comparable to the arrive-to-wait time found in a New Zealand study of 7 minutes (137). A similar investigation could not be found for Danish commuters but the 8 minutes are regarded as reasonable in this context. Those having shorter distances to a stop get a longer permitted wait time which may be favorable in terms of entering more services within the 20 minutes. This, though, reflect the difference in the service level.

The accessibility measure does not include how many jobs that are accessible within the accessibility area, which has been included in other studies. Individual profession or job type is not known and therefore integrating this in the analyses may not add to the understanding of choosing active commuting to work or study.

5.4.11 *Unmeasured confounding*

A number of confounders identified in other studies was not included in this study. Car ownership is often a strong predictor in analyses of travel mode choice (104). It was not included in this study as it was not the aim to investigate how car ownership affects active commuting. Health measures such as general health state, disability and chronic diseases may affect travel choice and it would be good to include those in further analyses.

6. Conclusions

The results of the present study suggest that provision of proximate and good public transportation services is associated with being an active commuter and with meeting the recommended levels of physical activity from active transportation alone. The results support the hypothesis that easy access to public transportation and high accessibility by public transportation play an important role in active commuting.

The proposed multimodal network model was designed to overcome the known challenges of handling time in a standard GIS network model. The model enabled integration of public transportation time schedules and the different components of travel time e.g. access, wait, in-vehicle, transfer and egress time. The constructed accessibility areas describe the potential for the individual to travel with public transportation in combination with walking or cycling within given time frames.

The wide range of new and known measures constructed in this thesis can contribute to the identification of the public transportation characteristics that facilitate the use of public transportation and associated active commuting. Ultimately this can be used as a guidance in transport planning to create more sustainable infrastructure solutions favouring active transport modes and reducing car-based commuting.

7. Perspectives

Active commuting is a unique opportunity to be routinely physically active and gain related health benefits. Planning a more sustainable transport system in the future, urban and transport planners need to focus on infrastructure that promote active commuting and reduces car-based commuting. However, which features of the built environment facilitate the different domains of active commuting? Future research should include information on which transport modes are used when commuting e.g. walking, cycling, public transportation in combination with active modes and car-based commuting. The Danish National Health Survey performed in 2013 has included transport mode choice so the data are readily available for these kinds of analyses. The survey is planned to be conducted every four years, which enables an evaluation of the stability and robustness of the associations over time. This opens the opportunity for studying temporal trends in the associations between the built environment and active commuting.

The multimodal model presented in this study provides the opportunity to perform further research within commuting patterns. Estimates of potential benefit from active commuting if shifting from car-based to active modes of commuting can be derived. The walk links in the multimodal network can easily be labelled so that it will be possible to calculate how much distance has been walked, cycled alone or in combination with public transportation. Future studies would therefore benefit from including information on individual working address to make simulation of commuting by the different transport modes from the home address to the work/study place possible.

The individual accessibility area is a very interesting aspect of the mobility, not only for commuting but also for leisure time activities, social interaction and access to public services. New methods are developing that make public transportation time schedules available for research in accessibility and transport choice studies. Salonen and Toivonen (92) used an API to obtain individual accessibility in Helsinki. This approach provides fast results based on updated time schedules. Recent developments within GIS integrate transit agencies' GTFS data feeds with network analyses tools (138). These new approaches will certainly enable many more to make accessibility studies.

The infrastructure is rapidly developing in The Capital Region of Denmark and it will likely have a great impact on the commuting patterns in the years to come. The construction of a metro ring around the Copenhagen City Core (139), a light rail combining the suburban city cores (140) and a double rail line from Copenhagen to Ringsted (141) will ease the travel to and around the metropolitan area with public transportation. Furthermore the introduction of super cycle highways (142) will make active commuting for longer commuting distances very attractive in the region. The impact of all these projects will potentially contribute to new exciting research in the years to come.

8. Reference List

(1) Pratt M, Sarmiento OL, Montes F, Ogilvie D, Marcus BH, Perez LG, et al. The implications of megatrends in information and communication technology and transportation for changes in global physical activity. Lancet 2012 Jul 21;380(9838):282-93.

(2) Lachapelle U, Frank L, Saelens BE, Sallis JF, Conway TL. Commuting by public transit and physical activity: where you live, where you work, and how you get there. J Phys Act Health 2011 Jan;8 Suppl 1:S72-S82.

(3) Sahlqvist S, Song Y, Ogilvie D. Is active travel associated with greater physical activity? The contribution of commuting and non-commuting active travel to total physical activity in adults. Prev Med 2012 Sep;55(3):206-11.

(4) Edwards RD. Public transit, obesity, and medical costs: assessing the magnitudes. Prev Med 2008 Jan;46(1):14-21.

(5) Villanueva K, Giles-Corti B, McCormack G. Achieving 10,000 steps: a comparison of public transport users and drivers in a university setting. Prev Med 2008 Sep;47(3):338-41.

(6) Wener R., Evans G. A morning stroll: Levels of physical activity in car and mass transit commuting. Environment and Behaviour 2007;39:62-74.

(7) Besser LM, Dannenberg AL. Walking to public transit: steps to help meet physical activity recommendations. Am J Prev Med 2005 Nov;29(4):273-80.

(8) Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. Lancet 2012 Jul 21;380(9838):219-29.

(9) WHO. Global Health Risks. Mortality and burden of disease attributable to selected major risks. 2009. Report No.: http://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf?ua=1 (accessed 15/6/2014).

(10) Brandt J, Jensen SS, Plejdrup M. Sundhedseffekter og relaterede eksterne omkostninger af luftforurening i København. Aarhus Universitet, DCE-Nationalt Center for Miljø og Energi, 46 s. - Videnskabelig rapport fra DCE - Nationalt Center for Miljø og Energi nr. 64 (In Danish). 2013 Jul 24.

(11) DTU. The Danish National Travel Survey. http://www.modelcenter.transport.www6.sitecore.dtu.dk/english/TU/Hovedresultater. 2013.
Ref Type: Online Source

(12) Dalton AM, Jones AP, Panter JR, Ogilvie D. Neighbourhood, Route and Workplace-Related Environmental Characteristics Predict Adults' Mode of Travel to Work. PLoS One 2013;8(6):e67575.

(13) Adams EJ, Goodman A, Sahlqvist S, Bull FC, Ogilvie D. Correlates of walking and cycling for transport and recreation: factor structure, reliability and behavioural associations of the perceptions of the environment in the neighbourhood scale (PENS). Int J Behav Nutr Phys Act 2013;10:87.

(14) Winters M, Brauer M, Setton EM, Teschke K. Built environment influences on healthy transportation choices: bicycling versus driving. J Urban Health 2010 Dec;87(6):969-93.

(15) Coogan PF, White LF, Adler TJ, Hathaway KM, Palmer JR, Rosenberg L. Prospective study of urban form and physical activity in the Black Women's Health Study. Am J Epidemiol 2009 Nov 1;170(9):1105-17.

(16) Li F, Harmer PA, Cardinal BJ, Bosworth M, Acock A, Johnson-Shelton D, et al. Built environment, adiposity, and physical activity in adults aged 50-75. Am J Prev Med 2008 Jul;35(1):38-46.

(17) Lovasi GS, Neckerman KM, Quinn JW, Weiss CC, Rundle A. Effect of individual or neighborhood disadvantage on the association between neighborhood walkability and body mass index. Am J Public Health 2009 Feb;99(2):279-84.

(18) McConville ME, Rodriguez DA, Clifton K, Cho G, Fleischhacker S. Disaggregate land uses and walking. Am J Prev Med 2011 Jan;40(1):25-32.

(19) Badland H., Hickey S., Bull F., Giles-Corti B. Public transport access and availability in the RESIDE study: is it taking us where we want to go? Journal of Transport & Health 2013;1:45-9.

(20) Stone J., Mees P. Planning public transport networks in the post-petroleum era. Australien Planner 2010;47:263-71.

(21) Kamada M, Kitayuguchi J, Inoue S, Kamioka H, Mutoh Y, Shiwaku K. Environmental correlates of physical activity in driving and non-driving rural Japanese women. Prev Med 2009 Dec;49(6):490-6.

(22) Dalvi M.Q., Martin K.M. The measurements of accessibility: some preliminary results. Transportation 1978;5:17-42.

(23) Frank LD, Greenwald MJ, Winkelman S, Chapman J, Kavage S. Carbonless footprints: promoting health and climate stabilization through active transportation. Prev Med 2010 Jan;50 Suppl 1:S99-105.

(24) Hoehner CM, Brennan Ramirez LK, Elliott MB, Handy SL, Brownson RC. Perceived and objective environmental measures and physical activity among urban adults. Am J Prev Med 2005 Feb;28(2 Suppl 2):105-16.

(25) Lachapelle U, Frank LD. Transit and health: mode of transport, employer-sponsored public transit pass programs, and physical activity. J Public Health Policy 2009;30 Suppl 1:S73-S94.

(26) Wasfi RA, Ross NA, El-Geneidy AM. Achieving recommended daily physical activity levels through commuting by public transportation: unpacking individual and contextual influences. Health Place 2013 Sep;23:18-25.

(27) McCormack GR, Giles-Corti B, Bulsara M. The relationship between destination proximity, destination mix and physical activity behaviors. Prev Med 2008 Jan;46(1):33-40.

(28) Pikora TJ, Giles-Corti B, Knuiman MW, Bull FC, Jamrozik K, Donovan RJ. Neighborhood environmental factors correlated with walking near home: Using SPACES. Med Sci Sports Exerc 2006 Apr;38(4):708-14.

(29) Hino AA, Reis RS, Sarmiento OL, Parra DC, Brownson RC. Built Environment and Physical Activity for Transportation in Adults from Curitiba, Brazil. J Urban Health 2013 Oct 5.

(30) Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep 1985 Mar;100(2):126-31.

(31) US Department of Health and Human Services. Physical Activity Guidelines Advisory Committee Report. 2008. Report No.: http://www.health.gov/paguidelines/Report/pdf/CommitteeReport.pdf (accessed May 12th 2014).

(32) Warburton DE, Charlesworth S, Ivey A, Nettlefold L, Bredin SS. A systematic review of the evidence for Canada's Physical Activity Guidelines for Adults. Int J Behav Nutr Phys Act 2010;7:39.

(33) WHO. Global recommendations on physical activity for health. Geneva: World Health Organisation . 2010.

(34) Sundhedsstyrelsen. Fysisk aktivitet - håndbog om forebyggelse og behandling. 2011. Report No.: http://sundhedsstyrelsen.dk/publ/Publ2012/BOFO/FysiskAktivitet/FysiskAktivitetHaandbog.pdf (Accessed May 12th 2014).

(35) Yamanouchi K, Shinozaki T, Chikada K, Nishikawa T, Ito K, Shimizu S, et al. Daily Walking Combined With Diet Therapy Is a Useful Means for Obese NIDDM Patients Not Only to Reduce Body Weight But Also to Improve Insulin Sensitivity. Diabetes Care 1995;18(6):775-8.

(36) Hatano Y. Use of pedometer for promoting daily walking exercise. International Council for Health Physical Education, Recreation 1993;29:4-8.

(37) Christensen AI, Ekholm O, Davidsen M, Juel K. Sundhed og sygelighed i Danmark 2010 & udviklingen siden 1987. Statens Institut for Folkesundhed, Syddansk Universitet. København; 2012.

(38) Aadahl M, Andreasen AH, Hammer-Helmich L, Buhelt L, Jorgensen T, Glumer C. Recent temporal trends in sleep duration, domain-specific sedentary behaviour and physical activity. A survey among 25-79-year-old Danish adults. Scand J Public Health 2013 Nov;41(7):706-11.

(39) Morabia A, Mirer FE, Amstislavski TM, Eisl HM, Werbe-Fuentes J, Gorczynski J, et al. Potential health impact of switching from car to public transportation when commuting to work. Am J Public Health 2010 Dec;100(12):2388-91.

(40) Audrey S, Procter S, Cooper AR. The contribution of walking to work to adult physical activity levels: a cross sectional study. Int J Behav Nutr Phys Act 2014;11(1):37.

(41) Sisson SB, Tudor-Locke C. Comparison of cyclists' and motorists' utilitarian physical activity at an urban university. Prev Med 2008 Jan;46(1):77-9.

(42) Saelens BE, Vernez MA, Kang B, Hurvitz PM, Zhou C. Relation between higher physical activity and public transit use. Am J Public Health 2014 May;104(5):854-9.

(43) Terzano K, Morckel V.C. Walk or Bike to a Healthier Life: Commuting Behaviour and Recreational Physical Activity. Environment and Behaviour 2011;43(4):488-500.

(44) Andersen LB, Schnohr P, Schroll M, Hein HO. All-cause mortality associated with physical activity during leisure time, work, sports, and cycling to work. Arch Intern Med 2000 Jun 12;160(11):1621-8.

(45) Hamer M, Chida Y. Active commuting and cardiovascular risk: a meta-analytic review. Prev Med 2008 Jan;46(1):9-13.

(46) Laverty AA, Mindell JS, Webb EA, Millett C. Active travel to work and cardiovascular risk factors in the United kingdom. Am J Prev Med 2013 Sep;45(3):282-8.

(47) Wen LM, Rissel C. Inverse associations between cycling to work, public transport, and overweight and obesity: findings from a population based study in Australia. Prev Med 2008 Jan;46(1):29-32.

(48) Gordon-Larsen P, Boone-Heinonen J, Sidney S, Sternfeld B, Jacobs DR, Jr., Lewis CE. Active commuting and cardiovascular disease risk: the CARDIA study. Arch Intern Med 2009 Jul 13;169(13):1216-23.

(49) Rojas-Rueda D, de NA, Teixido O, Nieuwenhuijsen MJ. Health impact assessment of increasing public transport and cycling use in Barcelona: a morbidity and burden of disease approach. Prev Med 2013 Nov;57(5):573-9.

(50) Saunders LE, Green JM, Petticrew MP, Steinbach R, Roberts H. What are the health benefits of active travel? A systematic review of trials and cohort studies. PLoS One 2013;8(8):e69912.

(51) Humphreys DK, Goodman A, Ogilvie D. Associations between active commuting and physical and mental wellbeing. Prev Med 2013 Aug;57(2):135-9.

(52) Montano DE, Kasprzyk D. Theory of Reasoned Action, Theory of Planned Behaviour, and the Integrated Behavioral Model. In: Glanz K, Rimer BK, Viswanath K, eds. Health behavior and health education: theory, research and practice. 4 ed. San Francisco CA. Jossey-Bass; 2008. p. 67-96.

(53) Bamberg S., Schmidt P. Regulating Transport: Behavioural Changes in the Field. Journal of Consumer Policy 1999;22:479-509.

(54) Bamberg S. Is a Residential Relocation a Good Opportunity to Change People's Travel Behaviour? Results From a Theory-Driven Intervention Study. Environment and Behaviour 2006;38:820-40.

(55) Taniguchi A, Fujii S. Promoting Public Transport Using Marketing Techniques in Mobility Management and Verifying their Quantitative Effects. Transportation 2007;34:37-49.

(56) Beale JR, Bonsall PW. Marketing in the Bus Industry: A Psychological Interpretation of Some Attitudinal and Behavioural Outcomes. Transportation Research Part F: Traffic Phychology and Behaviour 2007;10:271-87.

(57) Bronfenbrenner U. Ecological models of human development.In International Encyclopedia of Education, Vol 3. 2nd ed. Oxford: Elsevier; 1994. p. 37-43.

(58) Sallis JF, Cervero RB, Ascher W, Henderson KA, Kraft MK, Kerr J. An ecological approach to creating active living communities. Annu Rev Public Health 2006;27:297-322.

(59) Sallis JF, Owen N, Fisher EB. Ecological models of health behavior. In: Glanz K, Rimer BK, Viswanath K, eds. Health behavior and health education: theory, research and practice. 4 th ed. San Francisco CA. Jossey-Bass; 2008. p. 465-82.

(60) Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJ, Martin BW. Correlates of physical activity: why are some people physically active and others not? Lancet 2012 Jul 21;380(9838):258-71.

(61) Giles-Corti B, Timperio A, Bull F, Pikora T. Understanding physical activity environmental correlates: increased specificity for ecological models. Exerc Sport Sci Rev 2005 Oct;33(4):175-81.

(62) Owen N, Humpel N, Leslie E, Bauman A, Sallis JF. Understanding environmental influences on walking; Review and research agenda. Am J Prev Med 2004 Jul;27(1):67-76.

(63) Pikora T, Giles-Corti B, Bull F, Jamrozik K, Donovan R. Developing a framework for assessment of the environmental determinants of walking and cycling. Soc Sci Med 2003 Apr;56(8):1693-703.

(64) Saelens BE, Sallis JF, Frank LD. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. Ann Behav Med 2003;25(2):80-91.

(65) Giles-Corti B, Donovan RJ. The relative influence of individual, social and physical environment determinants of physical activity. Soc Sci Med 2002 Jun;54(12):1793-812.

(66) Dijstra EW. A Note on Two Problems in Connexion with Graphs. Numerische Matematik 1959;1:269-71.

(67) Landex A, Hansen S, Andersen JLE. Examination of catchment areas for public transport. Trafikdage på Aalborg Universitet 2006;1-16.

(68) El-Geneidy A, Grimsrud M, Wasfi R, Tétreault P, Surprenant-Legault J. New evidence on walking distances to transit stops: Identifying redundancies and gaps using variable service areas. Transportation 2014;41(1):193-210.

(69) Handy SL, Boarnet MG, Ewing R, Killingsworth RE. How the built environment affects physical activity: views from urban planning. Am J Prev Med 2002 Aug;23(2 Suppl):64-73.

(70) Kansky K. Structure of transportation networks: relationship between network geometry and regional characteristics. University of Chicago, Department of Geography, Research Papers 84; 1963.

(71) Levinson D. Network structure and city size. PLoS One 2012;7(1):e29721.

(72) Hess PM, Moudon AV, Snyder MC, Stanilov K. Site Design and Pedestrian Travel. Transp Res Record 1999;1674:9-19.

(73) Cervero R, Kockelman K. Travel demand and the 3D´s: density, diversity, and design. Transp Res D 1997;2:199-219.

(74) Berrigan D, Pickle LW, Dill J. Associations between street connectivity and active transportation. Int J Health Geogr 2010;9:20.

(75) Frank LD, Sallis JF, Saelens BE, Leary L, Cain K, Conway TL, et al. The development of a walkability index: application to the Neighborhood Quality of Life Study. Br J Sports Med 2010 Oct;44(13):924-33.

(76) Owen N, De DB, I, Sugiyama T, Leslie E, Cerin E, Van Van DD, et al. Bicycle use for transport in an Australian and a Belgian city: associations with built-environment attributes. J Urban Health 2010 Mar;87(2):189-98.

(77) Van DD, Cardon G, Deforche B, Sallis JF, Owen N, De B, I. Neighborhood SES and walkability are related to physical activity behavior in Belgian adults. Prev Med 2010 Jan;50 Suppl 1:S74-S79.

(78) Van DD, De MF, Cardon G, Deforche B, De B, I. Physical environmental attributes and active transportation in Belgium: what about adults and adolescents living in the same neighborhoods? Am J Health Promot 2013 May;27(5):330-8.

(79) Madsen T, Schipperijn J, Troelsen J, Christiansen LB, Duncan S, Nielsen TS. Associations between neighbourhood walkability and cycling in Denmark. Cycling Reseach International 2013;3:154-70.

(80) Eluru N, Chakour V, El-Geneidy AM. Travel mode choice and transit route choice behavior in Montreal. Public Transp 2012;4:129-49.

(81) Morency C., Trépanier M., Demers M. Walking to transit: An unexpected source of physical activity. Transport Policy 2011;18:800-6.

(82) Giles-Corti B, Donovan RJ. Socioeconomic status differences in recreational physical activity levels and real and perceived access to a supportive physical environment. Prev Med 2002 Dec;35(6):601-11.

(83) Cerin E, Leslie E, Owen N. Explaining socio-economic status differences in walking for transport: an ecological analysis of individual, social and environmental factors. Soc Sci Med 2009 Mar;68(6):1013-20.

(84) Sallis JF, Saelens BE, Frank LD, Conway TL, Slymen DJ, Cain KL, et al. Neighborhood built environment and income: examining multiple health outcomes. Soc Sci Med 2009 Apr;68(7):1285-93.

(85) Turrell G, Haynes M, Burton NW, Giles-Corti B, Oldenburg B, Wilson LA, et al. Neighborhood disadvantage and physical activity: baseline results from the HABITAT multilevel longitudinal study. Ann Epidemiol 2010 Mar;20(3):171-81.

(86) van Lenthe FJ, Brug J, Mackenbach JP. Neighbourhood inequalities in physical inactivity: the role of neighbourhood attractiveness, proximity to local facilities and safety in the Netherlands. Soc Sci Med 2005 Feb;60(4):763-75.

(87) Benenson I, Martens K, Rofé Y, Kwartler A. Public transport versus private car GIS-based estimation of accessibility applied to the Tel Aviv metropolitan area. Annals of Regional Science 2011;47(3):499-515.

(88) Hess DB. Access to Employment for Adults in Poverty in the Buffalo-Niagara Region. Urban Studies 2005;42(7):1177-200.

(89) Kawabata M. Spatiotemporal dimensions of modal accessiblity disparity in Boston and San Francisco. Environment and Planning A 2009;41:183-98.

(90) Kawabata M, Shen Q. Job accessibility as an indicator of auto-oriented urban structure: a comparison of Boston and Los Angeles with Tokyo. Environment and Planning B: Planning and Design 2014;33:115-30.

(91) Kwok R, Yeh AGO. The use of modal accessibility gap as an indicator for sustainable transport development. Environment and Planning A 2004;36:921-36.

(92) Salonen M, Toivonen T. Modelling travel time in urban networks: comparable measures for private car and public transport. Journal of Transport Geography 2013;31:143-53.

(93) Shen Q. Location characteristics of inner-city neighbourhoods and employment accessibility of low-wage workers. Environment and Planning B: Planning and Design 1998;25(3):345-65.

(94) Hansen WG. How Accessibility Shapes Land Use. Journal of the American Institute of Planners 1959;25:73-6.

(95) Handy SL, Niemeier DA. Measuring accessibility: an exploration of issues and alternatives. Environment and Planning A 1997;29:1175-94.

(96) Geurs KT, van Wee B. Accessibility evaluation of land-use and transport strategies: review and research directions. Journal of Transport Geography 2004;12:127-40.

(97) Dong X, Ben-Akiva ME, Bowman JL, Walker JL. Moving from trip-based to activity-based measures of accessibility. Transportation Research Part A 2006;40:163-80.

(98) Lei TL, Church RL. Mapping transit-based access: integrating GIS, routes and schedules. International Journal of Geographical Information Science 2010;24(2):283-304.

(99) Ben-Akiva ME, Lerman S. Discrete choice analysis. Cambridge, MA: MIT Press; 1985.

(100) Pirie GH. Measuring accessibility: a review and proposal. Environment and Planning A 1979;11:299-312.

(101) Hägerstrand T. What about people in regional science? People of the regional science association 1970;24:7-21.

(102) Blumenberg E, Ong P. Cars, Buses, and Jobs. Transportation Research Record 1999;1756:22-31.

(103) Tribby CP, Zandbergen PA. High-resolution spatio-temporal modeling of public transit accessibility. Applied Geography 2012;34:345-55.

(104) Eluru N, Chakour V, El-Geneidy AM. Travel mode choice and transit route choice behaviour in Montreal: insights from McGill university members commute patterns. Public Transp 2012;4(2):129-49.

(105) Pratt RH, Evans JE. Bus Routing and coverage. TCRP Report 95: traveler response to transportation system changes. Washington, DC: Transportation Research Board; 2004.

(106) Liu S, Zhu X. Accessibility Analyst: an integrated GIS tool for accessibility analysis in urban transportation planning. Environment and Planning B: Planning and Design 2004;31(1):105-24.

(107) O'Sullivan D, Morrison A, Shearer J. Using desktop GIS for the investigation of accessibility by public transport: an isochrone approach. International Journal of Geographical Information Science 2000;14(1):85-104.

(108) Mavoa S, Witen K, McCreanor T, O'Sullivan D. GIS based destination accessibility via public transit and walking in Auckland, New Zealand. Journal of Transport Geography 2012;20:15-22.

(109) Gent C, Symonds G. Advances in public transportation accessibility assessments for development control - a proposed methodology. PTRC AnnualTransport Practitioners' Meeting, UK, 2005.

(110) Martin.D., Jordan H, Roderick P. Taking the bus: incorporating public transport timetable data into health care accessibility modelling. Environment and Planning A 2008;40:2510-25.

(111) Peipins LA, Graham S, Young R, Lewis B, Foster S, Flanagan B, et al. Time and distance barriers to mammography facilities in the Atlanta metropolitan area. J Community Health 2011 Aug;36(4):675-83.

(112) Krygsman S, Dijst M, Arentze T. Multimodal public transport: an analysis of travel time elements and the interconncectivity ratio. Transport Policy 2004;11:265-75.

(113) de Jonge B, Teunter RH. Optimizing itineraries in public transportation with walks between rides. Transportation Research Part B: Methodological 2013;55:212-26.

(114) Egnsplankontoret. Skitseforslag til egnsplan for Storkøbenhavn (Copenhagen Finger Plan). Copenhagen, Denmark: Tutein & Koch; 1947.

(115) Knowles RD. Transit oriented Development in Copenhagen, Denmark: from the Finger Plan to Ørestad. Journal of Transport Geography 2012;22:251-61.

(116) Christensen AI, Ekholm O, Glumer C, Andreasen AH, Hvidberg MF, Kristensen PL, et al. The Danish National Health Survey 2010. Study design and respondent characteristics. Scand J Public Health 2012 Jun;40(4):391-7.

(117) Pedersen CB, Gotzsche H, Moller JO, Mortensen PB. The Danish Civil Registration System. A cohort of eight million persons. Dan Med Bull 2006 Nov;53(4):441-9.

(118) Jensen VM, Rasmussen AW. Danish Education Registers. Scand J Public Health 2011 Jul;39(7 Suppl):91-4.

(119) Baadsgaard M, Quitzau J. Danish registers on personal income and transfer payments. Scand J Public Health 2011 Jul;39(7 Suppl):103-5.

(120) Petersson F, Baadsgaard M, Thygesen LC. Danish registers on personal labour market affiliation. Scand J Public Health 2011 Jul;39(7 Suppl):95-8.

(121) Bang-Jensen J, Gutin G. Digraphs: Theory, Algorithms and Applications. 2 ed. Springer; 2008.

(122) Region Hovedstaden. Transportvaner i hovedstadsregionen. Hvad fortæller den nationale Transportvane Undersøgelse (TU)? (in danish). 2009. Report No.: version 2.0.

(123) Gropp KM, Pickett W, Janssen I. Multi-level examination of correlates of active transportation to school among youth living within 1 mile of their school. Int J Behav Nutr Phys Act 2012;9:124.

(124) Larsen K, Merlo J. Appropriate assessment of neighborhood effects on individual health: integrating random and fixed effects in multilevel logistic regression. Am J Epidemiol 2005 Jan 1;161(1):81-8.

(125) Merlo J, Yang M, Chaix B, Lynch J, Rastam L. A brief conceptual tutorial on multilevel analysis in social epidemiology: investigating contextual phenomena in different groups of people. J Epidemiol Community Health 2005 Sep;59(9):729-36.

(126) Merlo J, Chaix B, Yang M, Lynch J, Rastam L. A brief conceptual tutorial of multilevel analysis in social epidemiology: linking the statistical concept of clustering to the idea of contextual phenomenon. J Epidemiol Community Health 2005 Jun;59(6):443-9.

(127) Merlo J, Chaix B, Yang M, Lynch J, Rastam L. A brief conceptual tutorial on multilevel analysis in social epidemiology: interpreting neighbourhood differences and the effect of neighbourhood characteristics on individual health. J Epidemiol Community Health 2005 Dec;59(12):1022-8.

(128) Merlo J, Chaix B, Ohlsson H, Beckman A, Johnell K, Hjerpe P, et al. A brief conceptual tutorial of multilevel analysis in social epidemiology: using measures of clustering in multilevel logistic regression to investigate contextual phenomena. J Epidemiol Community Health 2006 Apr;60(4):290-7.

(129) Grewal R, Cote JA, Baumgartner H. Multicollinearity and measurement error in structural equation models: implication for theory testing. Market Sci 2004;23:519-29.

(130) Badland HM, Schofield GM, Schluter PJ. Objectively measured commute distance: associations with actual travel modes and perceptions to place of work or study in Auckland, New Zealand. J Phys Act Health 2007 Jan;4(1):80-6.

(131) Brenner PS, DeLamater JD. Social Desirability Bias in Self-reports of Physical Activity: Is an Exercise Identity Culprit? Soc Indic Res 2014;117:489-504 DOI 10.1007/s11205-013-0359-y.

(132) Boone-Heinonen J, Diez Roux AV, Kiefe CI, Lewis CE, Guilkey DK, Gordon-Larsen P. Neighborhood socioeconomic status predictors of physical activity through young to middle adulthood: the CARDIA study. Soc Sci Med 2011 Mar;72(5):641-9.

(133) Cressie NA. Change of Support and the modifiable areal unit problem. Geographical Systems 1996;3:159-80.

(134) Openshaw S. The modifiable areal unit problem. Norwick: Geo Books; 1983.

(135) Spielman SE, Yoo EH. The spatial dimensions of neighborhood effects. Soc Sci Med 2009 Mar;68(6):1098-105.

(136) Ye X, Pendyala R, Giovanni G. An exploration of the relationship between mode choice and complexity of trip chaining patterns. Transp Res,Part B, Methodol 2007;41:96-112.

(137) Lester T, Waltman D. Arrival characteristics of passengers intending to use public transport. In: 32nd Australasian Transport Research Forum, Auckland, New Zealand 2010.

(138) Morang M. Yay transit http://transit.melindamorang.com/index.html. 2014.

Ref Type: Online Source

(139) Metro City Ring. http://intl.m.dk/#!/about+the+metro/cityringen/about. 2014.
Ref Type: Online Source

(140) Ring3 (in danish). http://www.ringtre.dk/letbane-ring-3/. 2014.
Ref Type: Online Source

(141) Bane.dk. http://uk.bane.dk/visBanearbejde_eng.asp?artikelID=15469. 2014.
Ref Type: Online Source

(142) Super cycle highways (in danish). http://www.supercykelstier.dk/. 2014.
Ref Type: Online Source

9. Appendices

A1: Literature review: associations between access to public transportation and active commuting

Author, study type	Study location, sample size	Outcome - active commuting	Objective public transport measure	Other built environment constructs	Confounders	Findings
Hino et al. (2013), Cross-sectional	Curitiba, Brasil, N = 1,206 (+18 years old)	Any walking for transport (≥ 10 min/week), Walking at recommended levels (≥ 150 min/week), Cycling for transportation at once for 10 minutes a week	1) Network distance to nearest bus stop. 2) Density of bus stops within 500 m network buffer. 3) Density of Bus Rapid transit Tube stations within 500 m network buffer.	Population density, Area income, Land use mix, Connectivity measures within 500 m buffer. 1) street density, meter road per square meter 2) avg. street length 3) # blocks 4) Proportion of dead-ends 5) Proportion of street intersections. # traffic lights within buffer. Terrain slope	Sex, age, BMI, education, marital status, car ownership	Only density of BRT tubes (≥2) were positively associated with any walking for transport (OR= 1.5 CI=1.22,1.84)
Hoehner et al. (2005), Cross-sectional	St. Louis, USA, N = 865 (18-96 years old)	1) engaged in any versus no transportation activity (walking or bicycling) , 2) Met/did not meet 30 min/day of walking or bicycling	1) % street segments with a bus or other transit stop (400 m radius from home)	Within 400m radius: Land use, #destinations, #parks with facilities, Presence of at least one bike lane, street safety score (connectivity, crossings, traffic ligth, street design)	age, gender, education	Segments with a bus stop was significantly associated with any transportation activity (OR=1.5 CI=1.0,2.3)
Li et al. (2008), Cross-sectional	Portland, USA, N =1,221 (English speaking 50 - 75 years old)	Walking for transportation (e.g. to catch a bus, light rail or train. Walked for household errands/transportation ≥ 30 min/week or not. Self-reported moderate-to-vigorous PA split in 3 categories: 1) met guidelines for PA 2) insufficiently active 3) sufficiently active	1) Density of public transit stations divided by area (census block)	Land use mix, Density of fast food outlets, #street intersections/mi^2, total acreage of green and open spaces	age, gender, race/ethnicity, employment status, home ownership, income, health status. Fruit & vegetable intake, fried food consumption, BMI, residential density, median household income, and % African American/Hispanic residents	Density of public transport stations significantly associated with more walking for transport (OR= 1.15 CI= 1.03,1.27) and being "sufficiently active" (OR= 1.07 CI=1.01,1.14)

Appendix 1 Continues >>

Author, study type	Study location, sample size	Outcome - active commuting	Objective public transport measure	Other built environment constructs	Confounders	Findings
Coogan et al. (2009), Longitudinal	NYC, Chicago, Illinois, LA, USA, N = 20,354 (African-American women 21-69 years old)	Hours/week spent in utilitarian walking (≥ 5h walking/week vs < 5h walking/week)	1) distance to nearest subway, train or ferry stop. 2) Length of bus routes within 0.5 mile network buffer.	Within a 0.5 mile network buffer from resident location: Housing density units/acre, Land use, Street Interconnectedness: Average block size, # intersections/mi2, ratio of 4-way to total intersections, Traffic as total length of major roads. Presence of sidewalks and distance to parks	age, BMI, smoking status, alcohol intake, parity, marital status, caregiver responsibilities, education, number of residential moves in the last 2 years, chronic disease, cancer at baseline, energy intake, TV viewing, % of vacant housing units, neighbothood SES, crime	Distance to nearest transit stop (OR=2.63 CI=2.29,3.03) and miles of bus route (OR=3.23 CI=2.83,3.68) is significantly positively associated with utilitarian walking. Miles of bus route is independently and significantly associated with utilitarian walking (OR=1.44 CI=1.21,1.72)
Lachapelle & Frank (2009), Cross-sectional	Atlanta, USA, N=4,156 (employed 16 - 70 years old)	3 classes of walking: 1) no walking, 2) moderate levels of walking < 2.4 km per day, 3) sufficient walking ≥ 2.4 km per day.	1) distance between nearest transit stop and the center of a 200m grid cell. 2) dichotomous variable of wether transit users lived within 450m and between 450 and 1 km of a transit stop		age, ethnicity, household income, net residential density, presence of retail stores, distance to transit, car availability	Transit users living 450 - 1000 meters of transit were significantly more likely to be moderate walkers (OR=6.54). Trips with public transport are significantly associated with being sufficiently active (OR=3.35) compared to driving or being a car passenger
Frank et al. (2010), Cross-sectional	Atlanta, USA, N = 10,148 (+16 years old)	Average kilocalories spent walking.	1) Network distance to nearest rail and bus stop based on centroid of 200m grid cell. 2) Transit accessibility (wether or not a travel survey household could access all the regions five major activity centers	Net residential area, Land use mix, intersection density (per km)	age, gender, ethnicity, Drivers' license status, Household income, #people in household, #vehicles in household	As shortest distance from rail increased energy expenditure from walking decreased. As shortest distance to nearest bus stop increased, energy expenditure from walking increased. Those having access to all 5 of the major city centres burned significantly more kilocalories from walking

Appendix 1 Continues >>

Author, study type	Study location, sample size	Outcome - active commuting	Objective public transport measure	Other built environment constructs	Confounders	Findings
McConville et al (2010), Cross-sectional	Montgomery County MD, USA, N=260 (Healthy adults)	Walking for transportation divided in 3 groups: 1) none, 2) < 150 min/week, 3)≥ 150 min/week	1) Network distance to bus stop and rail station. 2) # Bus stops within 1/4 mile or 1/2 mile	Distance to: Bank, Fast-food restaurant, grocery store, library, night use, office, parks, PA use, recreation center, restaurant, retail, school, social use, sports facility. Residential population density (people/acre), sidewalk density (feet/acre), neighbourhood type	age, gender, education, population density, sidewalk density within 1/4 mile, Neighbourhood type	Compared to not walking, the adjusted odds for walking for transportation for < 150 minutes/week were significantly lower with greater distance to rail station (OR=0.91 CI=0.85,0.97). Compared to not walking, walking for transportation for ≥ 150 minutes/week were siginificantly lower for greater distances to closest bus stop (OR=0.01 CI=0.001,0.11) and rail station (OR=0.9 CI=0.82,0.99). Compared to not walking, the odds for walking for transportation < 150 minutes/week were significantly higher with density of bus stops within 1/2 mile (OR=1.05 CI=1.01,1.08). Compared to not walking, the odds for walking for transportation ≥ 150 minutes/week were significantly higher with density of bus stops within 1/4 (OR=1.16 CI=1.12,1.20) and 1/2 mile (OR=1.06 CI=1.00,1.11).
Wasfi et al. (2013), Cross-sectional	Montreal, CAN, N= 6913 (+18 years old)	Calculated daily walking distance	1) Type of transit used (bus, train, metro), 2) Transit service characteristics; time between every two consecutive transit vehicles, Transit service runs only in the morning	Population density, retail density, #street intersections within 500m of trip origin	age, gender, income, education level, population density, land use density and diversity, street intersections	Each trip conducted with a commuter train contributed to daily walking distances with 1319.29. Busses 899.53, metro: 633.84. 11 % of commuters achieved recommended PA just by walking to and from transit to work or school

Appendix 1 Continues >>

Author, study type	Study location, sample size	Outcome - active commuting	Objective public transport measure	Other built environment constructs	Confounders	Findings
Kamada et al. (2009), Cross-sectional	Unnan City, Japan, N= 434 (40-64 years old rural Japanese women)	1) sufficiently active (engaged in 150 min or more of moderate or 60 min of vigorous intensity PA per week). 2) insufficiently active. 3) inactive	1) Euclidian distances from each neighbourhood community location to nearest train station and bus stop. 2) Bus service frequency for the nearest stop at community level. 3) Categorization of bus convenience based on distance and service frequency at nearest stop	Perceived measures: access to transit, shops, sidewalk, bike lane, residential density, traffic safety and aesthetics	age, BMI, gender, general health state, household income, employment, farming, driving status, caregiving status	Sufficiently active women are more likely to report good access to transit compared to non-active. Non-drivers in an area with moderately convenient bus services are more likely to be sufficiently active than those where services were less convenient (OR=3.23 CI=1.00,10.41)
Pikora et al. (2006), Cross-sectional	Perth, AUS, N=1,678 (18-59 years old)	Any walking for transport (to and from work) in the previous 2 weeks	1) Public transport within 400 m circular buffer of home. Embedded in destination score	Walkability score, Street design: Grid, Modified grid, Cul-de-sac, distance between intersections	demographic, individual, social, physical environmental factors, area SES	Presence of public transport wihtin 400 meters from home was not significantly associated with walking for transport (OR=1.2). Presence of destinations was significantly related to walking for transport near home (OR=1.8). Walkability score was significantly associated with walking for transport (OR=1.95)
McCormack et al (2007), Cross-sectional (18-59 years old)	Perth, AUS, N=1,394 (18-59 years old)	3 classes of any walking for transport in the past 2 weeks: 1) inactive, 2)irregular (only reporting walking at one survey), 3) regular walking (walking reported at both surveys). For regular and irregular walking for transport a duration of walking was calculated	1) Shortest road network distance to bus stops and transit stations. Variables were derived as: 1) Bus stop/transit station present within 400 meters of home, 2) Bus stop/transit station present within 1500 meters of home	Presence within 400 and 1500 meters: shops, post boxes, convenience stores, newsagents, schools, parks, the river, beaches, Perth metropolitan area. Destination mix as a cumulative opportunity of different destinations wihtin 400 m and 1500 m.	sex, age, area level social disadvantage, education, number of children ≤ 18 years, BMI	Residing 400 m (OR=1.66 CI=1.17,2.37) within a bus stop and 400m (OR=5.0 CI=1.18, 21.25) and 1500m (OR=2.38 CI=1.67,3.39) within a transit station was significantly associated with regular walking for transport among regular and irregular walkers vs incative. Residing 1500m within a transit station (OR=1.50 CI=1.09,2.05) was significantly associated with irregular walking for transport vs inactive >>

Author, study type	Study location, sample size	Outcome - active commuting	Objective public transport measure	Other built environment constructs	Confounders	Findings
Badland et al. (2013), Longitudinal	Perth, AUS, N=238 (>18 years old)	Self-reported usual commute mode to work. PMV, PT, Walk/cycle, Multimodal.	1) Nearest bus stop to residence and workplace. 2) Nearest rail stop to residence and workplace. 3) Density of public transport stops within 400 m network buffer from residence and workplace. 4) 3 categories for access to nearest bus (400m) and rail (800m). Tertiles of bus stops were used to describe density of stops		sex, children present in household	Compared to those only having proximate residential PT access, respondents having only proximate workplace PT access (OR=11.57) or had both proximate residence and workplace PT (OR=16.51) were significantly more likely to commute to work using PT modes. Only PT density around the working place were significantly associated with commuting by PT (OR=25.77)
Dalton et al. (2013), Cross-sectional	Cambridge, UK, N=1,155 (+16 years old)	RPAQ Used to classify participants according to their usual mode of travel to work: car - motor vehicle, public transport, bicycle or walking.	1) Bus service to work. 2) Distance to nearest stop from home and work. 3) Bus service Frequency at home and work. 4) Nearest railway station at home and work. 5) Number of bus stops at and work within 800 meter network buffer- 6) Number of bus routes (work)	Distance to work, Route directness to work, Direction of travel, Proportion of A and B roads %, Road density, Junction density, Road connectivity, Existence of A roads, proportion % of food/cycle paths, effective walkable area. Land use mix, Building density, Number of destinations, deprivation, car parking availability	age, gender, limiting illness, deprivation, education, children in the household, car ownership, type of work, roads and routes, land use	Greater distance to a railway station at home were associated with lower odds of cycling (OR=0.53) and public transport use (OR=0.38). A greater distance to the nearest bus stop (0.39) and a lower bus frequency (0.32) were associated with lower odds of public transport use.

A2: Paper I: Results from the associations between access to public transportation and meeting recommended levels of physical activity. Subgroup analyses for distance to work, age and gender for both being an active commuter and meeting recommendations of physical activity.

Associations between access to public transportation and meeting recommended levels of physical activity

Table A2-1 Crude and adjusted associations (OR) between objective distance measures to public transportation and meeting recommended levels of physical activity. Between-neighbourhood variation is expressed by the Intra-class correlation coefficient (ICC). Significant associations are highlighted in bold text.

	Model 1: Crude	**Model 2: Model 1 + Individual co-variates**	**Model 3: Model 2 + Neighbourhood co-variates**
	OR (CI)	OR (CI) [b]	OR (CI) [c]
Distance to bus stop (km)	**0.8 (0.71 - 0.90)**	**0.81 (0.72 - 0.91)**	**0.86 (0.76 - 0.96)**
P-value [a]	*0.0002*	*0.0005*	*0.0099*
ICC	*11.9*	*10.6*	*2.1*
Distance to bus stop (m)			
Close (≤ 200)	1.00	1.00	1.00
Moderate Close (201 - 400)	1.01 (0.95 - 1.07)	1.01 (0.95 - 1.07)	1.02 (0.96 - 1.08)
Moderate Far(401 - 800)	0.94 (0.87 - 1.01)	0.95 (0.88 - 1.02)	0.98 (0.91 - 1.05)
Far (>800)	**0.75 (0.63 - 0.88)**	**0.75 (0.63 - 0.89)**	0**.79 (0.67 - 0.94)**
P-value [a]	*0.0010*	*0.0028*	*0.0183*
ICC	*12.0*	*10.7*	*2.1*
Distance to train station (km)	**0.94 (0.93 - 0.96)**	**0.95 (0.93 - 0.97)**	**0.98 (0.97 - 0.99)**
P-value [a]	*<0.0001*	*<0.0001*	*0.001*
ICC	*10.9*	*9.7*	*2.1*
Distance to train station (m)			
Close (0 - 500)	1.00	1.00	1.00
Medium Close (501 - 1000)	1.08 (0.90 - 1.29)	1.11 (0.92 - 1.33)	1.13 (0.95 - 1.35)
Medium Far (1001 - 3000)	1.03 (0.87 - 1.23)	1.05 (0.88 - 1.26)	1.06 (0.90 - 1.26)
Far (>3000)	0.88 (0.72 - 1.07)	0.92 (0.75 - 1.11)	0.99 (0.83 - 1.18)
P-value [a]	*0.0101*	*0.0236*	*0.1254*
ICC	*12.2*	*10.7*	*2.1*
Distance to S-train station (m)			
Close (0 - 500)	1.00	1.00	1.00
Medium Close (501 - 1000)	1.02 (0.91 - 1.13)	1.03 (0.93 - 1.15)	1.03 (0.93 - 1.15)
Medium Far (1001 - 3000)	0.90 (0.80 - 1.00)	0.93 (0.83 - 1.04)	0.96 (0.86 - 1.07)
Far (>3000)	**0.64 (0.55 - 0.75)**	**0.64 (0.55 - 0.75)**	**0.87 (0.76 - 1.00)**
P-value [a]	*0.0017*	*<0.0001*	*0.0260*
ICC	*9.3*	*7.8*	*1.9*
Distance to metro stop (m)			
Close (0 - 500)	1.00	1.00	1.00
Medium Close (501 - 1000)	1.03 (0.87 - 1.21)	1.03 (0.88 - 1.22)	1.04 (0.88 - 1.22)
Medium Far (1001 - 3000)	0.93 (0.77 - 1.12)	0.97 (0.81 - 1.17)	1.05 (0.89 - 1.24)
Far (>3000)	0.42 (0.35 - 0.51)	**0.45 (0.37 - 0.54)**	0.74 (0.61 - 0.88)
P-value [a]	*0.0017*	*<0.0001*	*<0.0001*
ICC	*5.8*	*4.9*	*1.7*

[a]P-value from type III test of the association.
[b]Bus distance adjusted for age, gender, education, bus routes and bus frequency. Train, S-train and metro adjusted for age, gender, education and distance to bus.
[c]Adjusted for population density, median income, street connectivity.

Table A2-2 Crude and adjusted associations (OR) between objective density measures of public transportation and meeting recommended levels of physical activity. Between-neighbourhood variation is expressed by the Intra-class correlation coefficient (ICC). Significant associations are highlighted in bold text.

	Model 1: Crude	**Model 2: Model 1 + Individual co-variates**	**Model 3: Model 2 + Neighbourhood co-variates**
	OR (CI)	OR (CI) [b]	OR (CI) [c]
Density of bus stops			
Low (0 - 5)	1.00	1.00	1.00
Medium low (6 - 10)	**1.19 (1.11 - 1.28)**	**1.21 (1.13 - 1.30)**	**1.16 (1.08 - 1.25)**
Medium high (11 - 15)	**1.38 (1.26 - 1.51)**	**1.39 (1.27 - 1.52)**	**1.22 (1.12 - 1.34)**
High (>15)	**1.64 (1.46 - 1.85)**	**1.66 (1.48 - 1.87)**	**1.22 (1.08 - 1.38)**
P-value [a]	*<0.0001*	*<0.0001*	*<0.0001*
ICC	*8.4*	*7.0*	*1.9*
Bus routes at stops within 1 km			
Low (0-2)	1.00	1.00	1.00
Medium low (3-4)	**1.10 (1.02 - 1.19)**	**1.13 (1.05 - 1.22)**	**1.09 (1.01 - 1.17)**
Medium High(5-6)	**1.30 (1.18 - 1.43)**	**1.33 (1.21 - 1.47)**	**1.18 (1.07 - 1.29)**
High (>6)	**1.32 (1.19 - 1.46)**	**1.38 (1.24 - 1.53)**	1.09 (0.98 - 1.22)
P-value [a]	*<0.0001*	*<0.0001*	*0.0082*
ICC	*9.8*	*7.9*	*2.0*
Transport mode index (TMI) 1 km			
0	**0.77 (0.60 - 0.98)**	**0.74 (0.58 - 0.96)**	0.78 (0.61 - 0.99)
1	1.00	1.00	1.00
2	**1.18 (1.10 - 1.27)**	**1.17 (1.09 - 1.26)**	**1.12 (1.04 - 1.19)**
3	**1.14 (1.00 - 1.3)**	1.12 (0.98 - 1.28)	1.07 (0.94 - 1.20)
P-value [a]	*<0.0001*	*<0.0001*	*0.0018*
ICC	*11.1*	*10.2*	*2.0*
Transport mode index (TMI) 3 km			
1	1.00	1.00	1.00
2	**1.29 (1.15 - 1.45)**	**1.28 (1.14 - 1.44)**	**1.16 (1.04 - 1.29)**
3	**1.70 (1.49 - 1.95)**	**1.70 (1.48 - 1.94)**	**1.38 (1.21 - 1.57)**
4	**2.79 (2.35 - 3.31)**	**2.75 (2.32 - 3.27)**	**1.44 (1.21 - 1.71)**
P-value [a]	*<0.0001*	*<0.0001*	*<0.0001*
ICC	*6.0*	*5.5*	*1.7*

[a]P-value from type III test of the association.
[b]Unique bus routes within 1 km adjusted for density of bus stops, age, gender and education. Density of bus stops adjusted for age, gender, education, bus routes at nearest stop and bus frequency at nearest stop. TMI 1 and 3 km adjusted for age, gender and education.
[c]Adjusted for population density, median income and street connectivity.
[d]The number represents number of transport modes within walking(1 km) and cycling distance (3 km).

Table A2-3 Crude and adjusted associations (OR) between objective measures of public transportation services and meeting recommended levels of physical activity. Between-neighbourhood variation is expressed by the Intra-class correlation coefficient (ICC). Significant associations are highlighted in bold text.

	Model 1: Crude	**Model 2: Model 1 + Individual co-variates**	**Model 3: Model 2 + Neighbourhood co-variates**
	OR (CI)	OR (CI)[b]	OR (CI)[c]
Bus routes at nearest stop			
Low (≤ 1)	1.00	1.00	1.00
Medium (2)	1.00 (0.93 - 1.06)	0.98 (0.92 - 1.05)	1.00 (0.93 - 1.07)
High (>2)	0.94 (0.87 - 1.01)	0.89 (0.81 - 0.98)	0.92 (0.84 - 1.01)
P-value[a]	*0.1362*	*0.0387*	*0.1372*
ICC	*12.7*	*10.6*	*2.1*
Frequency of bus service at nearest stop			
Low (0-2)	1.00	1.00	1.00
Medium-low (3 - 6)	**0.91 (0.84 - 0.99)**	0.92 (0.85 - 1.00)	0.95 (0.88 - 1.03)
Medium-high (7 - 15)	0.98 (0.90 - 1.06)	1.02 (0.93 - 1.11)	1.00 (0.92 - 1.09)
High (> 15)	0.98 (0.90 - 1.07)	1.06 (0.96 - 1.19)	0.99 (0.89 - 1.10)
P-value[a]	*0.1142*	*0.0176*	*0.5287*
ICC	*12.3*	*10.2*	*2.1*
Frequency of bus services at "best stop"			
Low (<= 10)	1.00	1.00	1.00
Medium low (11 - 20)	**1.19 (1.09 - 1.30)**	**1.15 (1.06 - 1.26)**	**1.10 (1.01 - 1.19)**
Medium high (21 - 40)	**1.37 (1.25 - 1.50)**	**1.28 (1.16 - 1.40)**	**1.16 (1.06 - 1.27)**
High (> 40)	**1.62 (1.46 - 1.81)**	**1.42 (1.26 - 1.60)**	**1.18 (1.05 - 1.32)**
P-value[a]	*<0.0001*	*<0.0001*	*0.0142*
ICC	*8.0*	*4.9*	*1.8*
Bus convenience at nearest stop			
Low (1)	1.00	1.00	1.00
Medium-low (2)	1.15 (1.04 - 1.27)	1.13 (1.03 - 1.25)	1.10 (1.00 - 1.21)
Medium-high (3)	1.05 (0.97 - 1.14)	1.06 (0.97 - 1.15)	1.05 (0.97 - 1.41)
High (4)	1.15 (1.05 - 1.25)	1.17 (1.07 - 1.29)	1.10 (1.00 - 1.21)
P-value[a]	*0.0042*	*0.0029*	*0.1591*
ICC	*12.7*	*10.8*	*2.1*
Bus convenience at "best" stop			
Low (1)	1.00	1.00	1.00
Medium-low (2)	1.01 (0.95 - 1.09)	1.00 (0.93 - 1.07)	0.98 (0.91 - 1.05)
Medium-high (3)	**1.13 (1.05 - 1.22)**	**1.10 (1.02 - 1.19)**	**1.07 (0.99 - 1.15)**
High (4)	**1.10 (0.99 - 1.23)**	**1.08 (0.96 - 1.22)**	**1.06 (0.94 - 1.19)**
P-value[a]	*0.0021*	*0.0191*	*0.0857*
ICC	*11.8*	*10.6*	*2.1*

[a]P-value from type III test of the association.
[b]Bus routes at nearest stop adjusted for distance to nearest bus stop, bus frequency at nearest stop, age, gender and education. Bus frequency at nearest bus stop adjusted for distance to nearest bus stop, bus routes at nearest stop, age, gender, education. Bus convenience at nearest stop adjusted for bus routes at nearest stop, age, gender and education. Bus frequency at "best" stop and Bus convenience at "best" stop adjusted for density of bus stops within 1 km, age, gender and education.
[c]Adjusted for population density, median income and street connectivity.

Subgroup analysis: Distance to work

Table A2-4 OR table for associations between objective distance measures to public transportation and being an active commuter modified by commute distance. Significant associations are highlighted in bold text.

	≤ 5 km OR (Cl)	**5 - 10 km** OR (Cl)	**10 - 20 km** OR (Cl)	**< 20 km** OR (Cl)
Distance to bus stop (km)	**0.53 (0.40 - 0.68)**	**0.53 (0.41 - 0.68)**	0.93 (0.74 - 1.18)	0.95 (0.80 - 1.14)
P-Value interaction = <0.0001				
Distance to bus stop (categories)				
Close (≤ 200)	1.00	1.00	1.00	1.00
Moderate Close (201 - 400)	0.90 (0.78 - 1.03)	1.02 (0.89 - 1.18)	1.03 (0.90 - 1.17)	1.12 (0.99 - 1.27)
Moderate Far(401 - 800)	**0.74 (0.62 - 0.88)**	**0.79 (0.67 - 0.93)**	1.10 (0.95 - 1.28)	1.02 (0.89 - 1.17)
Far (>800)	**0.51 (0.35 - 0.74)**	**0.46 (0.32 - 0.65)**	**0.72 (0.53 - 0.98)**	1.09 (0.86 - 1.40)
P-Value interaction = <0.0001				
Distance to train station (km)	**0.95 (0.93 - 0.97)**	**0.97 (0.95 - 0.99)**	0.99 (0.97 - 1.00)	0.99 (0.98 - 1.00)
P-Value interaction = 0.0010				
Distance to train station (categories)				
Close (0 - 500)	1.00	1.00	1.00	1.00
Medium Close (501 - 1000)	0.96 (0.60 - 1.54)	1.18 (0.75 - 1.86)	1.07 (0.71 - 1.60)	0.82 (0.60 - 1.12)
Medium Far (1001 - 3000)	0.74 (0.48 - 1.13)	1.16 (0.77 - 1.76)	0.91 (0.63 - 1.32)	**0.72 (0.53 - 0.96)**
Far (>3000)	**0.56 (0.36 - 0.86)**	0.99 (0.66 - 1.49)	0.98 (0.68 - 1.42)	**0.68 (0.51 - 0.90)**
P-Value interaction = 0.0022				
Distance to S-train station (m)				
Close (0 - 500)	1.00	1.00	1.00	1.00
Medium Close (501 - 1000)	1.15 (0.88 - 1.50)	0.90 (0.71 - 1.14)	1.03 (0.80 - 1.32)	1.13 (0.86 - 1.48)
Medium Far (1001 - 3000)	0.84 (0.66 - 1.08)	0.83 (0.66 - 1.04)	0.85 (0.67 - 1.07)	1.06 (0.83 - 1.37)
Far (>3000)	**0.73 (0.56 - 0.95)**	0.82 (0.63 - 1.05)	**0.77 (0.60 - 0.99)**	1.12 (0.86 - 1.45)
P-Value interaction = 0.139				
Distance to metro stop (m)				
Close (0 - 500)	1.00	1.00	1.00	1.00
Medium Close (501 - 1000)	0.80 (0.52 - 1.23)	1.09 (0.70 - 1.69)	0.73 (0.45 - 1.19)	0.84 (0.50 - 1.38)
Medium Far (1001 - 3000)	0.79 (0.59 - 1.17)	1.11 (0.75 - 1.65)	0.68 (0.44 - 1.06)	0.63 (0.40 - 1.00)
Far (>3000)	**0.43 (0.30 - 0.64)**	**0.59 (0.40 - 0.86)**	0.74 (0.49 - 1.12)	0.89 (0.57 - 1.40)
P-Value interaction = <0.0001				

Table A2-5 OR table for associations between objective distance measures to public transportation and meeting recommended levels of physical activity modified by commute distance. Significant associations are highlighted in bold text.

	≤ 5 km OR (Cl)	**5 - 10 km** OR (Cl)	**10 - 20 km** OR (Cl)	**< 20 km** OR (Cl)
Distance to bus stop (km)	**0.67 (0.53 - 0.85)**	**0.67 (0.52 - 0.86)**	1.04 (0.82 - 1.32)	1.03 (0.85 - 1.25)
P-Value interaction = 0.0019				
Distance to bus stop (categories)				
Close (≤ 200)	1.00	1.00	1.00	1.00
Moderate Close (201 - 400)	0.96 (0.87 - 1.06)	0.96 (0.85 - 1.07)	1.06 (0.94 - 1.20)	1.14 (1.00 - 1.29)
Moderate Far(401 - 800)	0.87 (0.76 - 0.99)	0.86 (0.75 - 0.99)	**1.15 (1.00 - 1.32)**	1.08 (0.93 - 1.25)
Far (>800)	**0.69 (0.49 - 0.97)**	**0.60 (0.42 - 0.86)**	0.81 (0.58 - 1.13)	1.04 (0.80 - 1.36)
P-Value interaction = 0.0186				
Distance to train station (km)	**0.97 (0.95 - 0.99)**	**0.96 (0.94 - 0.98)**	0.99 (0.97 - 1.01)	1.00 (0.99 - 1.02)
P-Value interaction = 0.0008				
Distance to train station (categories)				
Close (0 - 500)	1.00	1.00	1.00	1.00
Medium Close (501 - 1000)	1.06 (0.78 - 1.44)	1.30 (0.88 - 1.93)	1.29 (0.87 - 1.90)	1.03 (0.75 - 1.42)
Medium Far (1001 - 3000)	0.99 (0.75 - 1.31)	1.35 (0.95 - 1.92)	1.15 (0.80 - 1.65)	0.89 (0.66 - 1.19)
Far (>3000)	0.84 (0.63 - 1.12)	1.22 (0.86 - 1.73)	1.27 (0.89 - 1.82)	0.89 (0.66 - 1.19)
P-Value interaction = 0.0230				
Distance to S-train station (m)				
Close (0 - 500)	1.00	1.00	1.00	1.00
Medium Close (501 - 1000)	1.04 (0.87 - 1.24)	1.17 (0.97 - 1.42)	0.91 (0.73 - 1.14)	0.98 (0.76 - 1.28)
Medium Far (1001 - 3000)	0.89 (0.76 - 1.06)	1.07 (0.89 - 1.29)	0.86 (0.69 - 1.06)	1.03 (0.80 - 1.32)
Far (>3000)	**0.81 (0.67 - 0.99)**	0.98 (0.79 - 1.20)	0.81 (0.65 - 1.03)	1.01 (0.78 - 1.30)
P-Value interaction = 0.2902				
Distance to metro stop (m)				
Close (0 - 500)	1.00	1.00	1.00	1.00
Medium Close (501 - 1000)	1.00 (0.79 - 1.26)	1.07 (0.76 - 1.49)	1.09 (0.73 - 1.62)	1.05 (0.67 - 1.64)
Medium Far (1001 - 3000)	1.12 (0.90 - 1.40)	1.10 (0.81 - 1.49)	1.01 (0.71 - 1.43)	0.80 (0.53 - 1.20)
Far (>3000)	**0.71 (0.57 - 0.89)**	**0.61 (0.45 - 0.81)**	1.07 (0.77 - 1.49)	1.00 (0.68 - 1.47)
P-Value interaction = <0.0001				

Table A2-6 OR table for associations between objective density measures of public transportation and being an active commuter modified by commute distance. Significant associations are highlighted in bold text.

	≤ 5 km OR (Cl)	**5 - 10 km** OR (Cl)	**10 - 20 km** OR (Cl)	**< 20 km** OR (Cl)
Density of bus stops				
Low (0 - 5)	1.00	1.00	1.00	1.00
Medium low (6 - 10)	**1.26 (1.07 - 1.48)**	**1.54 (1.32 - 1.79)**	**1.20 (1.06 - 1.37)**	1.10 (0.97 - 1.24)
Medium high (11 - 15)	**1.59 (1.31 - 1.92)**	**1.66 (1.39 - 1.99)**	1.11 (0.94 - 1.31)	0.99 (0.84 - 1.17)
High (>15)	**2.29 (1.82 - 2.87)**	**1.95 (1.57 - 2.43)**	1.11 (0.88 - 1.38)	0.96 (0.78 - 1.19)
P-Value interaction = <0.0001				
Bus routes at stops within 1 km				
Low (0-2)	1.00	1.00	1.00	
Medium low (3-4)	**1.27 (1.08 - 1.49)**	**1.36 (1.16 - 1.58)**	0.97 (0.85 - 1.11)	1.06 (0.93 - 1.21)
Medium High(5-6)	**1.52 (1.25 - 1.84)**	**1.68 (1.39 - 2.02)**	0.97 (0.81 - 1.15)	1.06 (0.88 - 1.28)
High (>6)	**1.83 (1.51 - 2.22)**	**1.46 (1.21 - 1.76)**	1.12 (0.93 - 1.34)	1.01 (0.84 - 1.21)
P-Value interaction = <0.0001				
Transport mode index (TMI) 1 km				
0	**0.52 (0.29 - 0.92)**	**0.42 (0.25 - 0.72)**	**0.54 (0.33 - 0.88)**	0.97 (0.70 - 1.36)
1	1.00	1.00	1.00	1.00
2	**1.34 (1.16 - 1.55)**	**1.22 (1.06 - 1.39)**	**1.21 (1.07 - 1.38)**	1.04 (0.91 - 1.19)
3	**2.24 (1.68 - 2.98)**	1.26 (0.99 - 1.62)	1.26 (0.97 - 1.64)	0.80 (0.60 - 1.06)
P-Value interaction = <0.0001				
Transport mode index (TMI) 3 km				
1	1.00	1.00	1.00	
2	**1.26 (1.01 - 1.57)**	1.14 (0.93 - 1.40)	1.15 (0.96 - 1.36)	**1.15 (1.00 - 1.33)**
3	**1.61 (1.26 - 2.05)**	**1.66 (1.32 - 2.08)**	1.17 (0.96 - 1.43)	0.91 (0.75 - 1.11)
4	**3.10 (2.27 - 4.25)**	**1.90 (1.40 - 2.57)**	1.15 (0.86 - 1.54)	0.99 (0.75 - 1.31)
P-Value interaction = <0.0001				

Table A2-7 OR table for associations between objective density measures of public transportation and meeting recommended levels of physical activity modified by commute distance. Significant associations are highlighted in bold text.

	≤ 5 km	**5 - 10 km**	**10 - 20 km**	**< 20 km**
	OR (Cl)	OR (Cl)	OR (Cl)	OR (Cl)
Density of bus stops				
Low (0 - 5)	1.00	1.00	1.00	1.00
Medium low (6 - 10)	1.11 (0.97 - 1.27)	**1.41 (1.22 - 1.63)**	**1.14 (1.01 - 1.30)**	1.03 (0.90 - 1.17)
Medium high (11 - 15)	**1.21 (1.04 - 1.40)**	**1.54 (1.31 - 1.81)**	1.04 (0.88 - 1.22)	1.08 (0.91 - 1.28)
High (>15)	**1.35 (1.15 - 1.59)**	**1.61 (1.34 - 1.94)**	0.88 (0.73 - 1.08)	0.88 (0.72 - 1.08)
P-Value interaction = <0.0001				
Bus routes at stops within 1 km				
Low (0-2)	1.00	1.00	1.00	1.00
Medium low (3-4)	1.02 (0.90 - 1.17)	**1.34 (1.17 - 1.55)**	1.01 (0.89 - 1.15)	1.05 (0.92 - 1.21)
Medium High(5-6)	**1.17 (1.01 - 1.35)**	**1.57 (1.34 - 1.85)**	0.98 (0.83 - 1.16)	1.04 (0.86 - 1.25)
High (>6)	**1.21 (1.05 - 1.40)**	**1.35 (1.15 - 1.58)**	0.88 (0.75 - 1.04)	0.92 (0.77 - 1.09)
P-Value interaction = <0.0001				
Transport mode index (TMI) 1 km				
0	0.74 (0.42 - 1.29)	**0.55 (0.31 - 0.97)**	**0.51 (0.28 - 0.92)**	1.09 (0.76 - 1.56)
1	1.00	1.00	1.00	1.00
2	**1.15 (1.04 - 1.28)**	**1.20 (1.07 - 1.35)**	1.11 (0.99 - 1.25)	1.01 (0.89 - 1.16)
3	**1.37 (1.16 - 1.63)**	1.07 (0.88 - 1.31)	0.90 (0.72 - 1.13)	**0.69 (0.52 - 0.90)**
P-Value interaction = 0.0001				
Transport mode index (TMI) 3 km				
1	1.00	1.00	1.00	1.00
2	**1.09 (0.90 - 1.32)**	**1.33 (1.10 - 1.62)**	1.08 (0.91 - 1.28)	1.15 (0.99 - 1.35)
3	**1.40 (1.13 - 1.71)**	**1.89 (1.53 - 2.33)**	1.09 (0.89 - 1.32)	0.92 (0.75 - 1.13)
4	**1.63 (1.29 - 2.07)**	**1.78 (1.38 - 2.29)**	0.90 (0.69 - 1.16)	1.00 (0.77 - 1.29)
P-Value interaction = <0.0001				

Table A2-8 OR table for associations between objective measures of public transportation services and being an active commuter modified by commute distance. Significant associations are highlighted in bold text.

	≤ 5 km OR (Cl)	**5 - 10 km** OR (Cl)	**10 - 20 km** OR (Cl)	**< 20 km** OR (Cl)
Bus routes at nearest stop				
Low (≤ 1)	1.00	1.00	1.00	1.00
Medium (2)	1.00 (0.86 - 1.16)	**0.87 (0.76 - 1.00)**	0.94 (0.83 - 1.07)	1.09 (0.96 - 1.24)
High (>2)	1.16 (0.96 - 1.39)	0.97 (0.81 - 1.17)	**0.88 (0.75 - 1.03)**	0.96 (0.82 - 1.11)
P-Value interaction = 0.0439				
Frequency of bus service at nearest stop				
Low (0-2)	1.00	1.00	1.00	1.00
Medium-low (3 - 6)	0.95 (0.79 - 1.14)	0.90 (0.75 - 1.08)	0.93 (0.79 - 1.09)	0.89 (0.77 - 1.03)
Medium-high (7 - 15)	1.11 (0.92 - 1.35)	1.08 (0.90 - 1.31)	0.96 (0.81 - 1.15)	0.87 (0.74 - 1.03)
High (> 15)	**1.24 (1.01 - 1.54)**	1.07 (0.87 - 1.32)	**0.78 (0.64 - 0.95)**	**0.78 (0.64 - 0.96)**
P-Value interaction = 0.0009				
Frequency of bus services at "best stop"				
Low (<= 10)	1.00	1.00	1.00	1.00
Medium low (11 - 20)	**1.25 (1.04 - 1.51)**	1.14 (0.95 - 1.36)	1.06 (0.91 - 1.23)	0.97 (0.84 - 1.11)
Medium high (21 - 40)	**1.28 (1.08 - 1.53)**	**1.35 (1.14 - 1.60)**	1.13 (0.97 - 1.31)	0.90 (0.77 - 1.05)
High (> 40)	**1.79 (1.46 - 2.19)**	**1.42 (1.16 - 1.73)**	1.03 (0.85 - 1.23)	0.93 (0.76 - 1.13)
P-Value interaction = <0.0001				
Bus convenience at nearest stop				
Low (1)	1.00	1.00	1.00	
Medium-low (2)	1.24 (0.99 - 1.56)	**1.39 (1.11 - 1.74)**	1.03 (0.84 - 1.25)	1.02 (0.85 - 1.21)
Medium-high (3)	**1.25 (1.03 - 1.52)**	**1.25 (1.04 - 1.50)**	0.95 (0.81 - 1.12)	0.95 (0.82 - 1.10)
High (4)	**1.60 (1.31 - 1.95)**	**1.58 (1.31 - 1.92)**	0.93 (0.78 - 1.10)	0.97 (0.82 - 1.14)
P-Value interaction = <0.0001				
Bus convenience at "best" stop				
Low (1)	1.00	1.00	1.00	
Medium-low (2)	1.11 (0.95 - 1.30)	1.10 (0.95 - 1.29)	0.90 (0.79 - 1.03)	1.00 (0.88 - 1.13)
Medium-high (3)	**1.20 (1.02 - 1.41)**	**1.21 (1.04 - 1.42)**	1.09 (0.95 - 1.26)	**0.85 (0.74 - 0.99)**
High (4)	1.29 (1.00 - 1.67)	**1.34 (1.03 - 1.73)**	0.82 (0.64 - 1.05)	**1.23 (0.92 - 1.64)**
P-Value interaction = 0.0008				

Table A2-9 OR table for associations between objective measures of public transportation services and meeting recommended levels of physical activity modified by commute distance. Significant associations are highlighted in bold text.

	≤ 5 km	**5 - 10 km**	**10 - 20 km**	**< 20 km**
	OR (Cl)	OR (Cl)	OR (Cl)	OR (Cl)
Bus routes at nearest stop				
Low (≤ 1)	1.00	1.00	1.00	1.00
Medium (2)	1.02 (0.91 - 1.14)	0.92 (0.82 - 1.05)	0.99 (0.88 - 1.12)	1.02 (0.89 - 1.16)
High (>2)	0.90 (0.79 - 1.02)	0.97 (0.83 - 1.13)	0.87 (0.75 - 1.01)	0.96 (0.82 - 1.11)
P-Value interaction = 0.6387				
Frequency of bus service at nearest stop				
Low (0-2)	1.00	1.00	1.00	1.00
Medium-low (3 - 6)	0.95 (0.82 - 1.09)	0.91 (0.78 - 1.07)	1.00 (0.86 - 1.17)	0.96 (0.82 - 1.11)
Medium-high (7 - 15)	0.96 (0.83 - 1.11)	0.99 (0.84 - 1.17)	1.08 (0.91 - 1.27)	0.99 (0.84 - 1.17)
High (> 15)	1.00 (0.86 - 1.17)	1.11 (0.93 - 1.33)	0.92 (0.76 - 1.11)	0.92 (0.75 - 1.11)
P-Value interaction = 0.2152				
Frequency of bus services at "best stop"				
Low (<= 10)	1.00	1.00	1.00	1.00
Medium low (11 - 20)	1.08 (0.93 - 1.26)	1.12 (0.95 - 1.32)	1.13 (0.98 - 1.32)	1.02 (0.88 - 1.19)
Medium high (21 - 40)	**1.18 (1.03 - 1.37)**	**1.41 (1.21 - 1.64)**	1.11 (0.96 - 1.28)	0.90 (0.77 - 1.05)
High (> 40)	**1.26 (1.08 - 1.48)**	**1.44 (1.21 - 1.72)**	0.91 (0.77 - 1.08)	0.99 (0.83 - 1.20)
P-Value interaction = <0.0001				
Bus convenience at nearest stop				
Low (1)	1.00	1.00		
Medium-low (2)	1.19 (0.99 - 1.43)	1.24 (1.01 - 1.52)	1.02 (0.84 - 1.24)	0.97 (0.80 - 1.17)
Medium-high (3)	1.11 (0.94 - 1.30)	1.09 (0.92 - 1.30)	1.05 (0.90 - 1.23)	0.98 (0.84 - 1.15)
High (4)	1.17 (1.00 - 1.38)	1.28 (1.08 - 1.52)	0.97 (0.83 - 1.15)	0.99 (0.84 - 1.17)
P-Value interaction = 0.1527				
Bus convenience at "best" stop				
Low (1)	1.00	1.00	1.00	1.00
Medium-low (2)	1.12 (0.99 - 1.27)	1.13 (0.99 - 1.3)	0.84 (0.74 - 0.95)	0.88 (0.77 - 1.00)
Medium-high (3)	1.11 (0.99 - 1.26)	**1.26 (1.10 - 1.44)**	1.01 (0.88 - 1.15)	0.90 (0.78 - 1.04)
High (4)	**1.06 (0.89 - 1.27)**	**1.40 (1.13 - 1.74)**	0.79 (0.63 - 1.00)	1.12 (0.86 - 1.45)
P-Value interaction = <0.0001				

Subgroup analysis: Age

Table A2-10 OR table for associations between objective distance measures to public transportation and being an active commuter modified by age. Significant associations are highlighted in bold text.

	16 - 29 years OR (Cl)	**30 - 45 years** OR (Cl)	**46 - 64 years** OR (Cl)
Distance to bus stop (km)	0.89 (0.65 - 1.20)	**0.74 (0.61 - 0.86)**	**0.73 (0.62 - 0.86)**
P-Value interaction = 0.5110			
Distance to bus stop (categories)			
Close (≤ 200)	1.00	1.00	1.00
Moderate Close (201 - 400)	1.02 (0.86 - 1.21)	**1.04 (0.94 - 1.15)**	1.01 (0.91 - 1.12)
Moderate Far(401 - 800)	1.20 (0.96 - 1.51)	**0.87 (0.77 - 0.98)**	0.92 (0.82 - 1.03)
Far (>800)	**0.58 (0.38 - 0.88)**	**0.89 (0.68 - 1.15)**	**0.66 (0.53 - 0.83)**
P-Value interaction = 0.0377			
Distance to train station (km)	0.99 (0.97 - 1.02)	**0.97 (0.96 - 0.98)**	**0.98 (0.96 - 0.99)**
P-Value interaction = 0.1353			
Distance to train station (categories)			
Close (0 - 500)	1.00	1.00	1.00
Medium Close (501 - 1000)	0.88 (0.55 - 1.41)	1.00 (0.72 - 1.37)	1.00 (0.75 - 1.34)
Medium Far (1001 - 3000)	1.18 (0.77 - 1.83)	0.80 (0.59 - 1.07)	0.84 (0.65 - 1.10)
Far (>3000)	1.02 (0.66 - 1.57)	**0.69 (0.51 - 0.92)**	0.77 (0.59 - 1.01)
P-Value interaction = 0.0164			
Distance to S-train station (m)			
Close (0 - 500)	1.00	1.00	1.00
Medium Close (501 - 1000)	1.05 (0.78 - 1.41)	1.09 (0.90 - 1.32)	0.97 (0.80 - 1.19)
Medium Far (1001 - 3000)	0.97 (0.73 - 1.28)	0.84 (0.70 - 1.01)	0.92 (0.76 - 1.11)
Far (>3000)	0.96 (0.71 - 1.29)	0.83 (0.67 - 1.02)	**0.77 (0.63 - 0.96)**
P-Value interaction = 0.1228			
Distance to metro stop (m)			
Close (0 - 500)	1.00	1.00	1.00
Medium Close (501 - 1000)	0.98 (0.63 - 1.52)	0.90 (0.64 - 1.26)	0.72 (0.47 - 1.09)
Medium Far (1001 - 3000)	0.99 (0.66 - 1.47)	**0.73 (0.53 – 1.00)**	0.70 (0.48 - 1.04)
Far (>3000)	0.96 (0.66 - 1.41)	**0.46 (0.34 - 0.63)**	**0.51 (0.35 - 0.74)**
P-Value interaction = <0.0001			

Table A2-11 OR table for associations between objective distance measures to public transportation and meeting recommended levels of physical activity modified by age. Significant associations are highlighted in bold text.

	16 - 29 years OR (Cl)	**30 - 45 years** OR (Cl)	**46 - 64 years** OR (Cl)
Distance to bus stop (km)	**0.67 (0.53 - 0.85)**	**0.79 (0.64 - 0.96)**	**0.80 (0.68 - 0.95)**
P-Value interaction = 0.0534			
Distance to bus stop (categories)			
Close (≤ 200)	1.00	1.00	1.00
Moderate Close (201 - 400)	1.11 (0.98 - 1.25)	0.98 (0.89 - 1.07)	1.03 (0.94 - 1.13)
Moderate Far(401 - 800)	**1.23 (1.04 - 1.44)**	**0.85 (0.75 - 0.95)**	1.01 (0.91 - 1.12)
Far (>800)	1.04 (0.71 - 1.52)	0.98 (0.75 - 1.27)	**0.61 (0.48 - 0.77)**
P-Value interaction = 0.0003			
Distance to train station (km)	1.00 (0.98 - 1.02)	**0.97 (0.95 - 0.98)**	0.99 (0.97 – 1.00)
P-Value interaction = 0.0025			
Distance to train station (categories)			
Close (0 - 500)	1.00	1.00	1.00
Medium Close (501 - 1000)	1.04 (0.73 - 1.49)	1.28 (0.96 - 1.70)	1.08 (0.82 - 1.42)
Medium Far (1001 - 3000)	1.20 (0.86 - 1.65)	1.10 (0.84 - 1.44)	0.99 (0.77 - 1.26)
Far (>3000)	1.17 (0.85 - 1.63)	0.97 (0.74 - 1.27)	0.97 (0.75 - 1.24)
P-Value interaction = 0.0444			
Distance to S-train station (m)			
Close (0 - 500)	1.00	1.00	1.00
Medium Close (501 - 1000)	1.02 (0.84 - 1.24)	1.03 (0.87 - 1.22)	1.04 (0.88 - 1.24)
Medium Far (1001 - 3000)	1.06 (0.87 - 1.28)	0.87 (0.74 - 1.02)	1.01 (0.86 - 1.20)
Far (>3000)	1.19 (0.95 - 1.47)	**0.82 (0.68 - 0.98)**	0.82 (0.68 - 0.99)
P-Value interaction = <0.0001			
Distance to metro stop (m)			
Close (0 - 500)	1.00	1.00	1.00
Medium Close (501 - 1000)	1.27 (0.96 - 1.69)	1.09 (0.86 - 1.39)	0.77 (0.56 - 1.04)
Medium Far (1001 - 3000)	1.12 (0.86 - 1.45)	1.06 (0.84 - 1.33)	0.92 (0.69 - 1.24)
Far (>3000)	1.05 (0.81 - 1.36)	**0.62 (0.49 - 0.78)**	**0.64 (0.48 - 0.86)**
P-Value interaction = <0.0001			

Table A2-11 OR table for associations between objective density measures of public transportation and being an active commuter modified by age. Significant associations are highlighted in bold text.

	16 - 29 years OR (CI)	**30 - 45 years** OR (CI)	**46 - 64 years** OR (CI)
Density of bus stops			
Low (0 - 5)	1.00	1.00	1.00
Medium low (6 - 10)	1.06 (0.86 - 1.32)	**1.35 (1.20 - 1.50)**	**1.20 (1.08 - 1.32)**
Medium high (11 - 15)	0.84 (0.67 - 1.07)	**1.38 (1.20 - 1.59)**	**1.40 (1.22 - 1.59)**
High (>15)	0.87 (0.67 - 1.13)	**1.81 (1.51 - 2.17)**	**1.48 (1.23 - 1.78)**
P-Value interaction = <0.0001			
Bus routes at stops within 1 km			
Low (0-2)	1.00	1.00	1.00
Medium low (3-4)	1.13 (0.91 - 1.39)	**1.24 (1.11 - 1.39)**	1.05 (0.95 - 1.17)
Medium High(5-6)	**0.76 (0.61 - 0.96)**	**1.38 (1.19 - 1.60)**	**1.41 (1.22 - 1.62)**
High (>6)	0.88 (0.70 - 1.10)	**1.46 (1.26 - 1.71)**	**1.29 (1.11 - 1.50)**
P-Value interaction = <0.0001			
Transport mode index (TMI) 1 km			
0	**0.44 (0.24 - 0.80)**	0.83 (0.56 - 1.21)	**0.63 (0.46 - 0.86)**
1	1.00	1.00	1.00
2	0.95 (0.80 - 1.13)	**1.36 (1.22 - 1.51)**	**1.14 (1.02 - 1.26)**
3	0.89 (0.67 - 1.18)	**1.65 (1.34 - 2.03)**	**1.28 (1.03 - 1.60)**
P-Value interaction = 0.0003			
Transport mode index (TMI) 3 km			
1	1.00	1.00	1.00
2	1.19 (0.91 - 1.56)	**1.17 (1.02 - 1.36)**	**1.16 (1.02 - 1.33)**
3	1.12 (0.84 - 1.51)	**1.45 (1.21 - 1.72)**	**1.41 (1.20 - 1.66)**
4	1.33 (0.93 - 1.89)	**2.10 (1.65 - 2.68)**	**1.82 (1.40 - 2.36)**
P-Value interaction = 0.0179			

Table A2-12 OR table for associations between objective density measures of public transportation and meeting recommended levels of physical activity modified by age. Significant associations are highlighted in bold text.

	16 - 29 years	**30 - 45 years**	**46 - 64 years**
	OR (Cl)	OR (Cl)	OR (Cl)
Density of bus stops			
Low (0 - 5)	1.00	1.00	1.00
Medium low (6 - 10)	1.16 (0.99 - 1.37)	**1.19 (1.06 - 1.33)**	**1.12 (1.02 - 1.23)**
Medium high (11 - 15)	0.89 (0.74 - 1.06)	**1.37 (1.20 - 1.56)**	**1.28 (1.13 - 1.44)**
High (>15)	0.88 (0.73 - 1.07)	**1.50 (1.28 - 1.75)**	1.13 (0.96 - 1.33)
P-Value interaction = <0.0001			
Bus routes at stops within 1 km			
Low (0-2)	1.00	1.00	1.00
Medium low (3-4)	0.95 (0.81 - 1.11)	**1.23 (1.10 - 1.38)**	1.03 (0.93 - 1.14)
Medium High(5-6)	**0.81 (0.68 - 0.97)**	**1.39 (1.21 - 1.59)**	**1.22 (1.07 - 1.39)**
High (>6)	**0.75 (0.63 - 0.88)**	**1.34 (1.17 - 1.54)**	1.07 (0.94 - 1.23)
P-Value interaction = <0.0001			
Transport mode index (TMI) 1 km			
0	0.70 (0.39 - 1.25)	0.95 (0.63 - 1.44)	**0.68 (0.48 - 0.97)**
1	1.00	1.00	1.00
2	0.90 (0.80 - 1.02)	**1.29 (1.17 - 1.42)**	1.09 (0.99 - 1.20)
3	**0.80 (0.65 - 0.97)**	**1.26 (1.06 - 1.49)**	1.06 (0.88 - 1.28)
P-Value interaction = 0.0001			
Transport mode index (TMI) 3 km			
1	1.00	1.00	1.00
2	1.01 (0.81 - 1.26)	**1.22 (1.04 - 1.42)**	1.13 (0.98 - 1.29)
3	0.94 (0.74 - 1.20)	**1.57 (1.31 - 1.86)**	**1.39 (1.19 - 1.64)**
4	0.93 (0.71 - 1.21)	**1.77 (1.43 - 2.20)**	**1.43 (1.14 - 1.78)**
P-Value interaction = <0.0001			

Table A2-13 OR table for associations between objective measures of public transportation services and being an active commuter modified by age. Significant associations are highlighted in bold text.

	16 - 29 years OR (Cl)	**30 - 45 years** OR (Cl)	**46 - 64 years** OR (Cl)
Bus routes at nearest stop			
Low (≤ 1)	1.00	1.00	1.00
Medium (2)	1.15 (0.95 - 1.38)	0.95 (0.85 - 1.06)	0.97 (0.88 - 1.08)
High (>2)	0.83 (0.67 - 1.02)	1.06 (0.92 - 1.22)	0.94 (0.83 - 1.07)
P-Value interaction = 0.0231			
Frequency of bus service at nearest stop			
Low (0-2)	1.00	1.00	1.00
Medium-low (3 - 6)	**1.29 (1.02 - 1.62)**	**0.85 (0.75 - 0.97)**	0.91 (0.81 - 1.03)
Medium-high (7 - 15)	1.04 (0.82 - 1.31)	0.92 (0.80 - 1.06)	1.08 (0.95 - 1.24)
High (> 15)	0.84 (0.66 - 1.07)	1.05 (0.89 - 1.23)	0.93 (0.79 - 1.09)
P-Value interaction = = <0.0001			
Frequency of bus services at "best stop"			
Low (<= 10)	1.00	1.00	1.00
Medium low (11 - 20)	**0.76 (0.60 - 0.97)**	1.09 (0.96 - 1.25)	**1.15 (1.03 - 1.30)**
Medium high (21 - 40)	**0.76 (0.61 - 0.95)**	**1.28 (1.12 - 1.46)**	**1.14 (1.01 - 1.29)**
High (> 40)	**0.73 (0.58 - 0.93)**	**1.35 (1.15 - 1.59)**	**1.36 (1.16 - 1.59)**
P-Value interaction = <0.0001			
Bus convenience at nearest stop			
Low (1)	1.00	1.00	1.00
Medium-low (2)	0.83 (0.61 - 1.11)	**1.19 (1.01 - 1.39)**	1.15 (0.99 - 1.33)
Medium-high (3)	1.06 (0.81 - 1.38)	1.03 (0.90 - 1.17)	1.07 (0.95 - 1.21)
High (4)	0.82 (0.63 - 1.06)	**1.26 (1.09 - 1.46)**	**1.26 (1.11 - 1.44)**
P-Value interaction = 0.0004			
Bus convenience at "best" stop			
Low (1)	1.00	1.00	1.00
Medium-low (2)	0.83 (0.68 - 1.02)	1.11 (0.99 - 1.24)	0.97 (0.88 - 1.08)
Medium-high (3)	**0.78 (0.64 - 0.95)**	**1.16 (1.03 - 1.31)**	1.12 (1.00 - 1.25)
High (4)	**0.66 (0.49 - 0.89)**	**1.41 (1.15 - 1.74)**	1.12 (0.91 - 1.37)
P-Value interaction = 0.0002			

Table A2-13 OR table for associations between objective measures of public transportation services and meeting recommended levels of physical activity modified by age. Significant associations are highlighted in bold text.

	16 - 29 years OR (Cl)	**30 - 45 years** OR (Cl)	**46 - 64 years** OR (Cl)
Bus routes at nearest stop			
Low (≤ 1)	1.00	1.00	1.00
Medium (2)	1.11 (0.97 - 1.27)	0.95 (0.85 - 1.05)	1.00 (0.91 - 1.10)
High (>2)	0.86 (0.74 - 1.00)	1.01 (0.89 - 1.14)	**0.87 (0.78 - 0.99)**
P-Value interaction = = 0.0203			
Frequency of bus service at nearest stop			
Low (0-2)	1.00	1.00	1.00
Medium-low (3 - 6)	**1.30 (1.10 - 1.54)**	**0.85 (0.75 - 0.97)**	0.92 (0.82 - 1.04)
Medium-high (7 - 15)	1.07 (0.90 - 1.27)	0.92 (0.81 - 1.05)	1.06 (0.93 - 1.20)
High (> 15)	0.97 (0.81 - 1.16)	1.06 (0.91 - 1.22)	0.95 (0.82 - 1.10)
P-Value interaction = <0.0001			
Frequency of bus services at "best stop"			
Low (<= 10)	1.00	1.00	1.00
Medium low (11 - 20)	0.84 (0.70 - 1.01)	1.12 (0.98 - 1.28)	**1.17 (1.04 - 1.31)**
Medium high (21 - 40)	0.79 (0.67 - 0.94)	**1.40 (1.23 - 1.59)**	**1.13 (1.01 - 1.27)**
High (> 40)	**0.72 (0.60 - 0.87)**	**1.39 (1.20 - 1.62)**	**1.25 (1.08 - 1.44)**
P-Value interaction = <0.0001			
Bus convenience at nearest stop			
Low (1)	1.00	1.00	
Medium-low (2)	0.82 (0.65 - 1.02)	**1.25 (1.06 - 1.46)**	1.10 (0.95 - 1.27)
Medium-high (3)	1.03 (0.85 - 1.26)	1.06 (0.92 - 1.21)	1.04 (0.93 - 1.17)
High (4)	**0.81 (0.67 - 0.99)**	**1.23 (1.07 - 1.42)**	1.14 (1.00 - 1.29)
P-Value interaction = <0.0001			
Bus convenience at "best" stop			
Low (1)	1.00	1.00	1.00
Medium-low (2)	**0.75 (0.65 - 0.87)**	**1.12 (1.01 - 1.25)**	0.97 (0.88 - 1.07)
Medium-high (3)	**0.78 (0.67 - 0.90)**	**1.21 (1.08 - 1.36)**	1.10 (0.99 - 1.22)
High (4)	**0.76 (0.61 - 0.93)**	**1.30 (1.09 - 1.54)**	1.01 (0.84 - 1.21)
P-Value interaction = <0.0001			

Subgroup analysis: Gender

Table A2-14 OR table for associations between objective distance measures to public transportation and being an active commuter as well as meeting recommended levels of physical activty modified by gender. Significant associations are highlighted in bold text.

	Active commuter (> 4min/day)		**Meeting recommended levels of physical activity (≥ 30min/day)**	
	Women	**Men**	**Women**	**Men**
	OR (Cl)	OR (Cl)	OR (Cl)	OR (Cl)
Distance to bus stop (km)	**0.53 (0.40 - 0.68)**	**0.82 (0.73 - 0.94)**	**0.75 (0.60 - 0.94)**	0.91 (0.80 - 1.04)
P-Value interaction = 0.3002			*P-Value =0.7097*	
Distance to bus stop (categories)				
Close (≤ 200)	1.00	1.00	1.00	1.00
Moderate Close (201 - 400)	1.04 (0.95 - 1.14)	1.00 (0.91 - 1.09)	1.00 (0.93 - 1.08)	1.04 (0.96 - 1.14)
Moderate Far(401 - 800)	**0.90 (0.80 - 1.00)**	0.95 (0.85 - 1.06)	0.94 (0.86 - 1.03)	1.03 (0.92 - 1.14)
Far (>800)	**0.62 (0.50 - 0.77)**	0.88 (0.70 - 1.10)	**0.68 (0.55 - 0.84)**	0.96 (0.76 - 1.22)
P-Value interaction = 0.0594			*P-Value =0.1276*	
Distance to train station (km)	**0.97 (0.96 - 0.98)**	0.99 (0.97 - 1.00)	**0.97 (0.96 - 0.99)**	0.99 (0.98 - 1.01)
P-Value interaction = 0.0316			*P-Value =0.0073*	
Distance to train station (categories)				
Close (0 - 500)	1.00	1.00	1.00	1.00
Medium Close (501 - 1000)	0.95 (0.73 - 1.25)	0.98 (0.74 - 1.30)	1.17 (0.93 - 1.47)	1.07 (0.82 - 1.40)
Medium Far (1001 - 3000)	0.88 (0.69 - 1.13)	0.84 (0.64 - 1.09)	1.11 (0.90 - 1.37)	1.00 (0.78 - 1.28)
Far (>3000)	**0.74 (0.58 - 0.95)**	**0.76 (0.58 - 0.99)**	0.97 (0.78 - 1.21)	1.01 (0.79 - 1.30)
P-Value interaction = 0.6368			*P-Value =0.0620*	
Distance to S-train station (m)				
Close (0 - 500)	1.00	1.00	1.00	1.00
Medium Close (501 - 1000)	0.87 (0.72 - 1.05)	1.18 (1.00 - 1.41)	0.93 (0.80 - 1.07)	**1.17 (1.00 - 1.36)**
Medium Far (1001 - 3000)	**0.73 (0.61 - 0.88)**	1.05 (0.89 - 1.23)	**0.84 (0.73 - 0.96)**	1.12 (0.97 - 1.30)
Far (>3000)	**0.65 (0.53 - 0.79)**	0.99 (0.82 - 1.19)	**0.75 (0.64 - 0.89)**	1.04 (0.87 - 1.24)
P-Value interaction = 0.0056			*P-Value =0.0116*	
Distance to metro stop (m)				
Close (0 - 500)	1.00	1.00	1.00	1.00
Medium Close (501 - 1000)	0.77 (0.55 - 1.10)	0.94 (0.69 - 1.27)	0.95 (0.76 - 1.19)	1.15 (0.91 - 1.45)
Medium Far (1001 - 3000)	**0.71 (0.52 - 0.99)**	0.84 (0.63 - 1.11)	1.04 (0.84 - 1.29)	1.06 (0.85 - 1.32)
Far (>3000)	**0.44 (0.32 - 0.61)**	**0.69 (0.52 - 0.92)**	**0.62 (0.50 - 0.78)**	0.90 (0.72 - 1.13)
P-Value interaction = 0.0007			*P-Value =<0.0001*	

Table A2-15 OR table for associations between objective density measures of public transportation and being an active commuter as well as meeting recommended levels of physical activty modified by gender. Significant associations are highlighted in bold text.

	Active commuter (> 4min/day)		**Meeting recommended levels of physical activity (≥ 30min/day)**	
	Women OR (Cl)	**Men** OR (Cl)	**Women** OR (Cl)	**Men** OR (Cl)
Density of bus stops				
Low (0 - 5)	1.00	1.00	1.00	1.00
Medium low (6 - 10)	**1.35 (1.23 - 1.49)**	**1.14 (1.03 - 1.26)**	**1.21 (1.10 - 1.32)**	1.10 (0.99 - 1.22)
Medium high (11 - 15)	**1.53 (1.35 - 1.74)**	1.11 (0.98 - 1.26)	**1.35 (1.21 - 1.51)**	1.07 (0.94 - 1.21)
High (>15)	**1.99 (1.67 - 2.38)**	1.17 (0.99 - 1.38)	**1.41 (1.23 - 1.62)**	1.01 (0.87 - 1.17)
P-Value interaction = <0.0001			*P-Value =<0.0001*	
Bus routes at stops within 1 km				
Low (0-2)	1.00	1.00	1.00	1.00
Medium low (3-4)	**1.15 (1.04 - 1.27)**	**1.11 (1.00 - 1.23)**	1.10 (1.00 - 1.20)	1.07 (0.96 - 1.19)
Medium High(5-6)	**1.47 (1.28 - 1.69)**	1.10 (0.96 - 1.25)	**1.24 (1.10 - 1.39)**	1.10 (0.97 - 1.25)
High (>6)	**1.57 (1.36 - 1.81)**	1.10 (0.95 - 1.27)	**1.24 (1.10 - 1.40)**	0.93 (0.82 - 1.06)
P-Value interaction = <0.0001			*P-Value =<0.0001*	
Transport mode index (TMI) 1 km				
0	**0.71 (0.53 - 0.95)**	**0.64 (0.45 - 0.90)**	0.79 (0.57 - 1.07)	0.77 (0.52 - 1.13)
1	1.00	1.00	1.00	1.00
2	**1.29 (1.17 - 1.42)**	1.10 (1.00 - 1.21)	**1.21 (1.11 - 1.32)**	1.01 (0.92 - 1.10)
3	**1.61 (1.32 - 1.98)**	1.14 (0.95 - 1.38)	**1.19 (1.03 - 1.39)**	0.93 (0.79 - 1.09)
P-Value interaction = 0.0079			*P-Value =0.0018*	
Transport mode index (TMI) 3 km				
1	1.00	1.00	1.00	1.00
2	**1.19 (1.04 - 1.35)**	**1.20 (1.04 - 1.38)**	**1.19 (1.05 - 1.36)**	1.10 (0.96 - 1.27)
3	**1.49 (1.27 - 1.75)**	**1.35 (1.14 - 1.59)**	**1.52 (1.31 - 1.77)**	**1.21 (1.02 - 1.42)**
4	**2.42 (1.90 - 3.07)**	**1.50 (1.19 - 1.89)**	**1.76 (1.45 - 2.14)**	1.12 (0.92 - 1.38)
P-Value interaction = <0.0001			*P-Value =<0.0001*	

Table A2-16 OR table for associations between objective measures of public transportation services and being an active commuter as well as meeting recommended levels of physical activty modified by gender. Significant associations are highlighted in bold text.

	Active commuter (> 4min/day)		**Meeting recommended levels of physical activity (≥ 30min/day)**	
	Women OR (Cl)	**Men** OR (Cl)	**Women** OR (Cl)	**Men** OR (Cl)
Bus routes at nearest stop				
Low (≤ 1)	1.00	1.00	1.00	1.00
Medium (2)	0.96 (0.87 - 1.06)	1.00 (0.91 - 1.11)	0.99 (0.91 - 1.08)	1.00 (0.91 - 1.10)
High (>2)	0.96 (0.85 - 1.09)	0.98 (0.86 - 1.12)	0.93 (0.84 - 1.04)	0.90 (0.80 - 1.02)
P-Value interaction = 0.8133			*P-Value = 0.8475*	
Frequency of bus service at nearest stop				
Low (0-2)	1.00	1.00	1.00	1.00
Medium-low (3 - 6)	0.94 (0.84 - 1.06)	0.91 (0.80 - 1.02)	0.92 (0.83 - 1.01)	1.01 (0.90 - 1.13)
Medium-high (7 - 15)	1.11 (0.97 - 1.26)	0.91 (0.80 - 1.03)	0.99 (0.89 - 1.11)	1.01 (0.89 - 1.14)
High (> 15)	1.07 (0.92 - 1.25)	**0.85 (0.73 - 0.99)**	1.07 (0.94 - 1.21)	0.91 (0.79 - 1.05)
P-Value interaction = 0.0098			*P-Value = 0.0030*	
Frequency of bus services at "best stop"				
Low (<= 10)	1.00	1.00	1.00	1.00
Medium low (11 - 20)	**1.15 (1.03 - 1.29)**	1.01 (0.90 - 1.14)	**1.14 (1.03 - 1.27)**	1.03 (0.92 - 1.17)
Medium high (21 - 40)	**1.27 (1.12 - 1.43)**	1.03 (0.91 - 1.16)	**1.23 (1.11 - 1.38)**	1.06 (0.94 - 1.19)
High (> 40)	**1.55 (1.33 - 1.81)**	1.02 (0.88 - 1.19)	**1.34 (1.18 - 1.53)**	0.99 (0.86 - 1.14)
P-Value interaction = <0.0001			*P-Value = 0.0002*	
Bus convenience at nearest stop				
Low (1)	1.00	1.00	1.00	1.00
Medium-low (2)	1.12 (0.98 - 1.29)	1.12 (0.97 - 1.30)	**1.14 (1.01 - 1.30)**	1.04 (0.90 - 1.20)
Medium-high (3)	**1.12 (1.00 - 1.26)**	0.99 (0.87 - 1.12)	1.09 (0.98 - 1.21)	1.00 (0.88 - 1.13)
High (4)	**1.37 (1.21 - 1.56)**	1.03 (0.90 - 1.18)	**1.20 (1.07 - 1.35)**	0.98 (0.86 - 1.11)
P-Value interaction = 0.0010			*P-Value =0.0385*	
Bus convenience at "best" stop				
Low (1)	1.00	1.00	1.00	1.00
Medium-low (2)	1.04 (0.94 - 1.14)	0.98 (0.88 - 1.08)	1.00 (0.92 - 1.09)	0.95 (0.86 - 1.05)
Medium-high (3)	**1.20 (1.08 - 1.34)**	0.97 (0.87 - 1.08)	**1.14 (1.04 - 1.25)**	0.97 (0.88 - 1.08)
High (4)	**1.23 (1.02 - 1.49)**	1.06 (0.88 - 1.27)	1.15 (0.99 - 1.33)	0.96 (0.82 - 1.13)
P-Value interaction = 0.0189			*P-Value =0.0431*	

A3: Paper III: Results from the associations between individual public transportation accessibility and meeting recommended levels of physical activity. Subgroup analyses for distance to work, age and gender for both being an active commuter and meeting recommendations of physical activity.

Table A3-1 Crude and adjusted associations (OR) between individual public transportation accessibility (using the nearest stop, all stops within walking distance or all stops within 3 km cycling distance) and meeting recommended levels of physical activity. Between-neighbourhood variation is expressed by the Intra-class correlation coefficient (ICC).

	Model 1: Crude	**Model 2: Model 1 + Individual co-variates**	**Model 3: Model 2 + Neighbourhood co-variates**
	OR (CI)	OR (CI)[b]	OR (CI)[c]
Nearest stop 30 minutes Acc.			
Low	1.00	1.00	1.00
Medium low	**0.92 (0.86 - 1.00)**	**0.92 (0.85 - 0.99)**	0.93 (0.87 - 1.01)
Medium high	0.99 (0.91 - 1.06)	1.00 (0.93 - 1.08)	0.98 (0.91 - 1.06)
High	1.03 (0.95 - 1.12)	1.06 (0.97 - 1.15)	0.97 (0.89 - 1.05)
P-value[a]	0.0832	0.0235	0.3233
ICC	*11.8*	*7.0*	*1.3*
Nearest stop 60 minutes Acc.			
Low	1.00	1.00	1.00
Medium low	0.99 (0.92 - 1.08)	1.01 (0.93 - 1.09)	1.03 (0.95 - 1.12)
Medium high	1.03 (0.95 - 1.12)	1.06 (0.98 - 1.15)	1.04 (0.96 - 1.12)
High	1.04 (0.94 - 1.14)	1.07 (0.98 - 1.18)	0.97 (0.88 - 1.06)
P-value[a]	0.7908	0.3134	0.4248
ICC	12.3	7.2	1.4
Stops within walking distance 30 minutes Acc. (1 km)			
Low	1.00	1.00	1.00
Medium low	**1.17 (1.08 - 1.26)**	**1.19 (1.10 - 1.29)**	**1.10 (1.02 - 1.19)**
Medium high	**1.41 (1.29 - 1.55)**	**1.45 (1.32 - 1.58)**	**1.22 (1.11 - 1.33)**
High	**1.48 (1.33 - 1.64)**	**1.55 (1.40 - 1.72)**	**1.15 (1.03 - 1.28)**
P-value[a]	<.0001	<.0001	0.0005
ICC	8.4	4.1	1.1
Stops wihtin walking distance 60 minutes Acc. (1 km)			
Low	1.00	1.00	1.00
Medium low	1.43 (1.31 - 1.57)	1.41 (1.29 - 1.53)	1.23 (1.12 - 1.34)
Medium high	1.82 (1.64 - 2.01)	1.76 (1.60 - 1.93)	1.37 (1.24 - 1.51)
High	2.17 (1.93 - 2.44)	2.12 (1.90 - 2.35)	1.36 (1.21 - 1.53)
P-value[a]	<.0001	<.0001	<.0001
ICC	5.3	2.6	0.9
Stops within cycling distance 30 minutes Acc. (3 km)			
Low	1.00	1.00	1.00
Medium low	1.58 (1.42 - 1.76)	1.44 (1.30 - 1.60)	1.18 (1.07 - 1.30)
Medium high	2.37 (2.12 - 2.66)	1.96 (1.76 - 2.18)	1.33 (1.19 - 1.49)
High	3.03 (2.69 - 3.42)	2.46 (2.20 - 2.76)	1.42 (1.25 - 1.61)
P-value[a]	<.0001	<.0001	<.0001
ICC	3.6	1.9	0.9
Stops within cycling distance 60 minutes Acc. (3 km)			
Low	1.00		1.00
Medium low	1.68 (1.51 - 1.87)	1.52 (1.37 - 1.69)	1.24 (1.12 - 1.37)
Medium high	2.11 (1.88 - 2.36)	1.78 (1.60 - 1.97)	1.28 (1.15 - 1.43)
High	3.29 (2.92 - 3.72)	2.67 (2.39 - 2.98)	1.47 (1.28 - 1.69)
P-value[a]	<.0001	<.0001	<.0001
ICC	3.3	2.1	0.9

[a]P-value from type III test of the association.
[b]Adjusted for age, gender, education, commute distance.
[c]Adjusted for population density, median income and street connectivity

Table A3-2 OR table for associations between public transport accessibility and being an active commuter modified by commute distance. Significant associations are highlighted in bold text.

	≤ 5 km OR (Cl)	5 - 10 km OR (Cl)	10 - 20 km OR (Cl)	> 20 km OR (Cl)
Nearest stop 30 minutes Acc.				
Low	1.00	1.00	1.00	1.00
Medium low	1.02 (0.86 - 1.21)	0.96 (0.81 - 1.14)	**0.83 (0.72 - 0.96)**	0.94 (0.83 - 1.07)
Medium high	1.08 (0.91 - 1.28)	**1.21 (1.03 - 1.43)**	0.89 (0.76 - 1.03)	1.00 (0.86 - 1.16)
High	**1.46 (1.21 - 1.76)**	**1.21 (1.01 - 1.44)**	0.87 (0.73 - 1.04)	**0.76 (0.63 - 0.91)**
P-Value interaction = <0.0001				
Nearest stop 60 minutes Acc.				
Low	1.00	1.00	1.00	1.00
Medium low	0.98 (0.83 - 1.17)	1.06 (0.89 - 1.26)	0.93 (0.81 - 1.08)	**1.15 (1.00 - 1.31)**
Medium high	1.09 (0.91 - 1.29)	1.14 (0.96 - 1.34)	0.92 (0.79 - 1.07)	1.01 (0.87 - 1.18)
High	**1.46 (1.21 - 1.77)**	**1.24 (1.04 - 1.49)**	0.85 (0.70 - 1.02)	0.75 (0.62 - 0.91)
P-Value interaction = <0.0001				
Stops within walking distance 30 minutes Acc. (1 km)				
Low	1.00	1.00	1.00	1.00
Medium low	**1.26 (1.05 - 1.50)**	**1.23 (1.03 - 1.46)**	**1.20 (1.05 - 1.39)**	1.08 (0.95 - 1.23)
Medium high	**1.56 (1.30 - 1.87)**	**1.35 (1.13 - 1.61)**	**1.33 (1.14 - 1.56)**	**1.25 (1.06 - 1.47)**
High	**1.94 (1.58 - 2.37)**	**1.63 (1.34 - 1.99)**	1.19 (0.99 - 1.44)	0.87 (0.71 - 1.06)
P-Value interaction = <0.0001				
Stops within walking distance 60 minutes Acc. (1 km)				
Low	1.00	1.00	1.00	1.00
Medium low	**1.31 (1.09 - 1.56)**	**1.25 (1.04 - 1.50)**	**1.24 (1.07 - 1.43)**	1.05 (0.92 - 1.21)
Medium high	**1.54 (1.28 - 1.86)**	**1.49 (1.24 - 1.80)**	**1.37 (1.17 - 1.61)**	1.18 (1.00 - 1.40)
High	**2.24 (1.80 - 2.78)**	**1.72 (1.40 - 2.12)**	**1.29 (1.06 - 1.58)**	0.89 (0.72 - 1.09)
P-Value interaction = <0.0001				
Stops within walking distance 30 minutes Acc. (3km)				
Low	1.00	1.00	1.00	1.00
Medium low	1.12 (0.93 - 1.36)	**1.22 (1.00 - 1.48)**	**1.40 (1.20 - 1.64)**	**1.18 (1.02 - 1.36)**
Medium high	**1.34 (1.10 - 1.64)**	**1.39 (1.15 - 1.69)**	**1.31 (1.10 - 1.56)**	0.85 (0.70 - 1.02)
High	**2.01 (1.60 - 2.51)**	**1.79 (1.43 - 2.24)**	**1.31 (1.06 - 1.62)**	0.85 (0.69 - 1.06)
P-Value interaction = <0.0001				
Stops within walking distance 60 minutes Acc. (3 km)				
Low	1.00	1.00	1.00	1.00
Medium low	1.15 (0.95 - 1.39)	**1.24 (1.02 - 1.51)**	**1.42 (1.21 - 1.67)**	1.12 (0.96 - 1.29)
Medium high	**1.28 (1.05 - 1.55)**	**1.40 (1.15 - 1.69)**	**1.34 (1.13 - 1.59)**	0.93 (0.78 - 1.11)
High	**2.14 (1.70 - 2.71)**	**1.97 (1.56 - 2.48)**	**1.25 (1.00 - 1.56)**	**0.79 (0.63 - 0.98)**
P-Value interaction = <0.0001				

Table A3-3 OR table for associations between public transport accessibility and meeting recommended levels of physical activity modified by commute distance. Significant associations are highlighted in bold text.

	≤ 5 km OR (Cl)	5 - 10 km OR (Cl)	10 - 20 km OR (Cl)	> 20 km OR (Cl)
Nearest stop 30 minutes Acc.				
Low	1.00	1.00	1.00	1.00
Medium low	0.91 (0.79 - 1.04)	0.88 (0.75 - 1.02)	0.96 (0.83 - 1.10)	0.99 (0.86 - 1.13)
Medium high	0.98 (0.86 - 1.12)	1.03 (0.89 - 1.19)	0.92 (0.79 - 1.06)	1.02 (0.87 - 1.19)
High	1.05 (0.92 - 1.20)	1.05 (0.91 - 1.22)	0.89 (0.76 - 1.04)	**0.73 (0.61 - 0.87)**
P-Value interaction = 0.0010				
Nearest stop 60 minutes Acc.				
Low	1.00	1.00	1.00	1.00
Medium low	0.93 (0.81 - 1.07)	0.88 (0.76 - 1.03)	1.13 (0.98 - 1.31)	1.18 (1.02 - 1.35)
Medium high	1.02 (0.89 - 1.17)	1.06 (0.91 - 1.22)	0.98 (0.84 - 1.13)	1.09 (0.93 - 1.28)
High	1.04 (0.91 - 1.19)	1.03 (0.88 - 1.20)	0.87 (0.73 - 1.03)	**0.75 (0.62 - 0.90)**
P-Value interaction = <0.0001				
Stops within walking distance 30 minutes Acc. (1 km)				
Low	1.00	1.00	1.00	1.00
Medium low	1.05 (0.90 - 1.21)	**1.18 (1.01 - 1.39)**	**1.17 (1.02 - 1.35)**	1.05 (0.92 - 1.20)
Medium high	**1.28 (1.11 - 1.49)**	**1.30 (1.11 - 1.53)**	1.14 (0.98 - 1.33)	1.17 (1.00 - 1.38)
High	**1.27 (1.09 - 1.49)**	**1.42 (1.19 - 1.69)**	0.98 (0.83 - 1.17)	0.79 (0.66 - 0.96)
P-Value interaction = <0.0001				
Stops within walking distance 60 minutes Acc. (1 km)				
Low	1.00	1.00	1.00	1.00
Medium low	**1.32 (1.13 - 1.53)**	**1.37 (1.16 - 1.62)**	**1.22 (1.05 - 1.41)**	1.12 (0.97 - 1.29)
Medium high	**1.51 (1.29 - 1.75)**	**1.59 (1.34 - 1.88)**	**1.31 (1.12 - 1.53)**	**1.20 (1.01 - 1.41)**
High	**1.69 (1.44 - 1.99)**	**1.69 (1.40 - 2.02)**	1.08 (0.90 - 1.30)	0.94 (0.78 - 1.14)
P-Value interaction = <0.0001				
Stops within walking distance 30 minutes Acc. (3km)				
Low	1.00	1.00	1.00	1.00
Medium low	1.11 (0.95 - 1.30)	**1.31 (1.10 - 1.57)**	**1.27 (1.09 - 1.48)**	**1.17 (1.02 - 1.36)**
Medium high	**1.45 (1.24 - 1.71)**	**1.73 (1.45 - 2.07)**	**1.28 (1.08 - 1.51)**	0.89 (0.74 - 1.08)
High	**1.64 (1.38 - 1.95)**	**1.91 (1.57 - 2.32)**	1.17 (0.96 - 1.41)	0.93 (0.76 - 1.13)
P-Value interaction = <0.0001				
Stops within walking distance 60 minutes Acc. (3 km)				
Low	1.00	1.00	1.00	1.00
Medium low	**1.20 (1.02 - 1.40)**	**1.42 (1.19 - 1.70)**	**1.36 (1.16 - 1.59)**	**1.17 (1.01 - 1.36)**
Medium high	**1.37 (1.17 - 1.61)**	**1.59 (1.33 - 1.90)**	**1.31 (1.11 - 1.55)**	0.97 (0.82 - 1.16)
High	**1.71 (1.43 - 2.05)**	**2.09 (1.71 - 2.56)**	1.13 (0.92 - 1.38)	0.94 (0.77 - 1.16)
P-Value interaction = <0.0001				

Table A3-4 OR table for associations between public transport accessibility and being an active commuter modified by age. Significant associations are highlighted in bold text.

	16 - 29 years OR (Cl)	30 - 45 years OR (Cl)	46 - 64 years OR (Cl)
Nearest stop 30 min			
Low	1.00	1.00	1.00
Medium low	1.09 (0.87 - 1.37)	0.94 (0.83 - 1.06)	0.90 (0.81 - 1.01)
Medium high	0.89 (0.71 - 1.10)	1.09 (0.96 - 1.24)	1.01 (0.90 - 1.14)
High	0.91 (0.73 - 1.13)	1.13 (0.98 - 1.31)	1.02 (0.89 - 1.18)
P-Value interaction = 0.0579			
Nearest stop 60 min			
Low	1.00	1.00	1.00
Medium low	1.18 (0.93 - 1.48)	1.08 (0.95 - 1.22)	1.00 (0.89 - 1.12)
Medium high	0.92 (0.74 - 1.14)	1.10 (0.97 - 1.26)	1.02 (0.90 - 1.15)
High	0.88 (0.71 - 1.10)	1.16 (1.00 - 1.34)	1.05 (0.91 - 1.23)
P-Value interaction = <0.0001			
Stops within walking distance 30 minutes Acc. (1 km)			
Low	1.00	1.00	1.00
Medium low	1.00 (0.79 - 1.26)	**1.23 (1.09 - 1.39)**	**1.15 (1.03 - 1.29)**
Medium high	0.97 (0.77 - 1.22)	**1.50 (1.31 - 1.72)**	**1.29 (1.13 - 1.46)**
High	0.91 (0.72 - 1.15)	**1.48 (1.26 - 1.74)**	**1.38 (1.18 - 1.62)**
P-Value interaction = 0.0806			
Stops within walking distance 60 minutes Acc. (1 km)			
Low	1.00	1.00	1.00
Medium low	0.91 (0.72 - 1.15)	**1.24 (1.09 - 1.41)**	**1.17 (1.04 - 1.31)**
Medium high	1.02 (0.81 - 1.29)	**1.51 (1.31 - 1.75)**	**1.27 (1.11 - 1.45)**
High	0.96 (0.75 - 1.22)	**1.60 (1.35 - 1.90)**	**1.45 (1.21 - 1.72)**
P-Value interaction = <0.0001			
Stops within cycling distance 30 minutes Acc. (3km)			
Low	1.00	1.00	1.00
Medium low	1.12 (0.89 - 1.43)	**1.28 (1.11 - 1.25)**	**1.16 (1.02 - 1.32)**
Medium high	0.98 (0.77 - 1.25)	**1.26 (1.08 - 1.48)**	**1.19 (1.02 - 1.38)**
High	1.04 (0.81 - 1.33)	**1.50 (1.25 - 1.80)**	**1.51 (1.26 - 1.81)**
P-Value interaction = 0.0462			
Stops within cycling distance 60 minutes Acc. (3 km)			
Low	1.00	1.00	1.00
Medium low	1.01 (0.80 - 1.28)	**1.27 (1.10 - 1.46)**	**1.15 (1.01 - 1.31)**
Medium high	0.98 (0.78 - 1.25)	**1.21 (1.04 - 1.40)**	**1.21 (1.05 - 1.39)**
High	1.06 (0.82 - 1.38)	**1.53 (1.26 - 1.85)**	**1.46 (1.21 - 1.77)**
P-Value interaction = <0.0001			

Table A3-5 OR table for associations between public transport accessibility and meeting recommended levels of physical activity modified by commute distance. Significant associations are highlighted in bold text.

	Age groups		
	OR (Cl) (16-29 years)	OR (Cl) (30-45 years)	OR (Cl) (46-64 years)
Nearest stop 30 min			
Low	1.00	1.00	1.00
Medium low	**1.28 (1.08 - 1.52)**	**0.87 (0.77 - 0.98)**	0.89 (0.80 - 0.99)
Medium high	0.95 (0.81 - 1.11)	1.06 (0.94 - 1.20)	0.93 (0.84 - 1.04)
High	0.90 (0.77 - 1.06)	1.02 (0.90 - 1.16)	0.96 (0.85 - 1.09)
P-Value interaction = <0.0001			
Nearest stop 60 min			
Low	1.00	1.00	1.00
Medium low	**1.22 (1.03 - 1.45)**	1.03 (0.91 - 1.17)	0.98 (0.88 - 1.09)
Medium high	0.95 (0.81 - 1.12)	**1.14 (1.01 - 1.29)**	1.00 (0.89 - 1.12)
High	0.84 (0.72 - 0.98)	1.06 (0.93 - 1.21)	0.96 (0.84 - 1.10)
P-Value interaction = 0.0035			
Stops within walking distance 30 minutes Acc. (1 km)			
Low	1.00	1.00	1.00
Medium low	0.87 (0.73 - 1.04)	**1.21 (1.07 - 1.37)**	**1.11 (1.00 - 1.24)**
Medium high	**0.84 (0.70 - 1.00)**	**1.48 (1.30 - 1.69)**	**1.18 (1.04 - 1.33)**
High	**0.75 (0.63 - 0.90)**	**1.36 (1.18 - 1.58)**	**1.17 (1.01 - 1.35)**
P-Value interaction = 0.0229			
Stops within walking distance 60 minutes Acc. (1 km)			
Low	1.00	1.00	1.00
Medium low	1.03 (0.86 - 1.23)	**1.34 (1.18 - 1.53)**	**1.21 (1.08 - 1.35)**
Medium high	0.99 (0.83 - 1.19)	**1.66 (1.45 - 1.90)**	**1.31 (1.16 - 1.48)**
High	0.93 (0.77 - 1.12)	**1.63 (1.40 - 1.90)**	**1.36 (1.18 - 1.58)**
P-Value interaction = <0.0001			
Stops within cycling distance 30 minutes Acc. (3km)			
Low	1.00	1.00	1.00
Medium low	1.15 (0.96 - 1.39)	**1.27 (1.11 - 1.46)**	1.11 (0.98 - 1.25)
Medium high	1.12 (0.93 - 1.35)	**1.48 (1.28 - 1.71)**	**1.29 (1.12 - 1.47)**
High	1.04 (0.86 - 1.26)	**1.63 (1.39 - 1.92)**	**1.46 (1.25 - 1.71)**
P-Value interaction = <0.0001			
Stops within cycling distance 60 minutes Acc. (3 km)			
Low	1.00	1.00	1.00
Medium low	1.10 (0.91 - 1.32)	**1.36 (1.18 - 1.56)**	**1.18 (1.04 - 1.34)**
Medium high	1.08 (0.90 - 1.30)	**1.38 (1.20 - 1.60)**	**1.26 (1.11 - 1.44)**
High	1.03 (0.85 - 1.26)	**1.69 (1.43 - 2.00)**	**1.51 (1.28 - 1.78)**
P-Value interaction = <0.0001			

Table A3-6 OR table for associations between public transport accessibility and being an active commuter modified by gender. Significant associations are highlighted in bold text.

	Women OR (Cl)	Men OR (Cl)
Nearest stop 30 min		
Low	1.00	1.00
Medium low	0.98 (0.88 - 1.09)	**0.89 (0.79 - 0.99)**
Medium high	1.12 (1.00 - 1.25)	0.93 (0.83 - 1.05)
High	**1.17 (1.03 - 1.34)**	0.93 (0.82 - 1.07)
P-Value interaction = <0.0332		
Nearest stop 60 min		
Low	1.00	1.00
Medium low	1.09 (0.98 - 1.22)	0.99 (0.89 - 1.12)
Medium high	1.10 (0.98 - 1.23)	0.97 (0.86 - 1.09)
High	**1.24 (1.08 - 1.43)**	0.91 (0.79 - 1.05)
P-Value interaction = 0.0058		
Stops within walking distance 30 minutes Acc. (1 km)		
Low	1.00	1.00
Medium low	**1.19 (1.07 - 1.32)**	**1.14 (1.02 - 1.28)**
Medium high	**1.41 (1.24 - 1.59)**	**1.24 (1.09 - 1.41)**
High	**1.63 (1.40 - 1.90)**	1.10 (0.94 - 1.27)
P-Value interaction = <0.0001		
Stops within walking distance 60 minutes Acc. (1 km)		
Low	1.00	1.00
Medium low	**1.18 (1.05 - 1.32)**	**1.14 (1.02 - 1.29)**
Medium high	**1.43 (1.26 - 1.63)**	**1.23 (1.08 - 1.40)**
High	**1.76 (1.50 - 2.08)**	1.15 (0.98 - 1.35)
P-Value interaction = <0.0001		
Stops within cycling distance 30 minutes Acc. (3km)		
Low	1.00	1.00
Medium low	**1.22 (1.08 - 1.38)**	**1.17 (1.03 - 1.34)**
Medium high	**1.34 (1.16 - 1.55)**	1.04 (0.90 - 1.21)
High	**1.77 (1.49 - 2.11)**	1.14 (0.96 - 1.35)
P-Value interaction = <0.0001		
Stops within cycling distance 60 minutes Acc. (3 km)		
Low	1.00	1.00
Medium low	**1.22 (1.07 - 1.38)**	1.13 (0.99 - 1.29)
Medium high	**1.32 (1.15 - 1.52)**	1.03 (0.90 - 1.19)
High	**1.81 (1.50 - 2.18)**	1.13 (0.94 - 1.35)
P-Value interaction = <0.0001		

Table A3-7 OR table for associations between public transport accessibility and meeting recommended levels of physical activity modified by gender. Significant associations are highlighted in bold text.

	Women OR (Cl)	Men OR (Cl)
Nearest stop 30 min		
Low	1.00	1.00
Medium low	0.94 (0.85 - 1.03)	0.94 (0.84 - 1.05)
Medium high	1.04 (0.94 - 1.15)	0.91 (0.82 - 1.02)
High	1.03 (0.93 - 1.15)	**0.88 (0.79 - 0.99)**
P-Value interaction = 0.0409		
Nearest stop 60 min		
Low	1.00	1.00
Medium low	1.03 (0.93 - 1.13)	1.05 (0.94 - 1.17)
Medium high	1.06 (0.96 - 1.17)	1.01 (0.90 - 1.13)
High	1.06 (0.95 - 1.19)	**0.86 (0.76 - 0.97)**
P-Value interaction = <0.0001		
Stops within walking distance 30 minutes Acc. (1 km)		
Low	1.00	1.00
Medium low	1.10 (1.00 - 1.22)	1.10 (0.98 - 1.23)
Medium high	**1.26 (1.13 - 1.41)**	**1.14 (1.01 - 1.29)**
High	**1.31 (1.15 - 1.48)**	0.94 (0.82 - 1.07)
P-Value interaction = <0.0001		
Stops within walking distance 60 minutes Acc. (1 km)		
Low	1.00	1.00
Medium low	**1.22 (1.10 - 1.35)**	**1.22 (1.08 - 1.37)**
Medium high	**1.45 (1.29 - 1.63)**	**1.24 (1.10 - 1.41)**
High	**1.55 (1.35 - 1.77)**	1.11 (0.96 - 1.29)
P-Value interaction = <0.0001		
Stops within cycling distance 30 minutes Acc. (3km)		
Low	1.00	1.00
Medium low	**1.17 (1.04 - 1.31)**	**1.17 (1.03 - 1.33)**
Medium high	**1.42 (1.25 - 1.61)**	**1.19 (1.04 - 1.37)**
High	**1.65 (1.42 - 1.90)**	1.14 (0.98 - 1.33)
P-Value interaction = <0.0001		
Stops within cycling distance 60 minutes Acc. (3 km)		
Low	1.00	1.00
Medium low	**1.26 (1.13 - 1.42)**	**1.17 (1.03 - 1.34)**
Medium high	**1.36 (1.21 - 1.54)**	**1.15 (1.00 - 1.31)**
High	**1.72 (1.48 - 2.00)**	1.16 (0.99 - 1.36)
P-Value interaction = <0.0001		

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Research article
The association between access to public transportation and self-reported active commuting

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Abstract: Active commuting provides routine-based regular physical activity during the week which can reduce risk of chronic diseases. Understanding how public transportation characteristics are associated with active transportation is thus important from a public health perspective. This study examines the associations between objective measures of access to public transportation and self-reported active commuting. Self-reported time spent either walking or cycling commuting each day and the distance to workplace were obtained for adults aged 16 to 65 in the Danish National Health Survey 2010 (N=28,928). Access to public transportation measures were computed by combining GIS-based road network distances from home address to public transit stops an integrating their service level. Multilevel logistic regression was used to examine the association between access to public transportation measures and active commuting. Distance to bus stop, density of bus stops, and number of transport modes were all positively associated with being an active commuter and with meeting recommendations of physical activity. No significant association was found between bus services at the nearest stop and active commuting. The results highlight the importance of including detailed measurements of access to public transit in order to identify the characteristics that facilitate the use of public transportation and active commuting.

Keywords: Active commuting; GIS, multi-level regression; travel planner data; origin-destination;

1. Introduction

There is convincing evidence that engaging in regular moderate-to-vigorous physical activity reduces the risks of obesity [1;2], cardiovascular diseases [3], diabetes [4] and premature death [5]. Active commuting is receiving increased attention in this context because its routine-based nature provides regular physical activity during the week. The major modes of active commuting are walking or cycling to work alone, or in combination with using public transportation, that involves some walking or cycling e.g. to a transit stop, transfers and a walk to the end location [6]. For longer commute trips, public transportation offers an active alternative to car-based commuting. Evidence has shown that active commuters are more likely to reach the WHO (2010) [7] recommendations of 150 minutes of moderate intensity physical activity (MPA) per week [8;9] and that transit users accumulate more MPA than non-users [10;11]. Studying local public transit characteristics that facilitate the use of public transportation thus addresses key information needed to promote active transportation.

Previous studies have established that the physical environment plays an important role in active commuting and associations have been found between active commuting and objective measures of the built environment, walking and biking facilities, street connectivity and proximity of destinations [12-14]. Furthermore, the commute distance has been found to be negatively associated with active commuting [15]. Several studies of access to public transportation and its association with active commuting have characterised access to public transportation by distance to the nearest stop [13;16-19] or density of stops within variable distances [20-24]. A few of these studies have found that distance to transit [13;17] is negatively associated and that density of stops [20;22-24] is positively associated with active commuting. However, additional relevant measures of public transportation access such as service frequency, route variation and meaningful destinations [25], have received much less attention. A few studies of the association between active commuting and public transportation include service frequency at the nearest stop [13;19] or available bus routes [13]. Only Dalton et al. [13] find a positive association between nearest bus stop service frequency and active commuting.

The aim of the present study was to examine the associations between a range of different objective measures of access to public transportation and self-reported active commuting in The Capital Region of Denmark. Transport service characteristics (service frequency, routes and transport modes) at the nearest, the best connected stop and all stops within walking distance were included in the objective measures. We further investigated if the associations were modified by the commute distance, age and gender.

2. Experimental Section

2.1 Study population and data sources

The study population comprised a subsample of the Danish National Health Survey 2010. The study design has been described in detail previously [26]. This paper focused on respondents living in The Capital Region of Denmark. The region includes urban, suburban and rural districts. A random sample of 95,150 was selected from the total population above 16 years of age living in the Capital Region of Denmark (1,355,000). Data was collected from February to April 2010 and the response rate was 52.3%. Selected respondents for this study were 16 to 64-year-olds either working or under education, with a commute distance of up to 200 km, living on the main island of Zealand who provided valid answers on commuting. This reduced the study sample to 28,928 respondents. The respondents´ home addresses were subsequently geocoded using the official Danish Address Register from the Danish Geodata Agency. The survey contained questions on health behaviour, including distance to and time spent walking or cycling to work or study each day. Individuals were invited to participate in the survey by answering an enclosed paper questionnaire and returning it by the mail, or online. In addition to the questionnaire, register-based data on individual respondents' age, gender, education and income were obtained from Statistics Denmark.

Two main geographical data sources were used in the study. Data on transit stop location, transport mode, routes and time schedules were obtained from www.rejseplanen.dk, the official search engine for information about public transportation in Denmark. The Capital Region of Denmark has four major transport modes: bus, train, s-train (light-rail) and metro. The data covered February to April 2010 in accordance with the time period of the questionnaire. Road networks were obtained from the Danish Geodata agency (Kort10) to conduct the walking distance measurements. Roads where walking or biking was not permitted (e.g. motorways, highways) were excluded from the dataset.

The Health Survey was reported to the Danish Data Protection Agency. Approval from the regional Committee on Health Research Ethics was not necessary as no human biological material was included in the data collection.

2.2. Definition of variables used in the study

2.2.1 Active commuting

The outcome variable was based on self-reported time spent walking or cycling to work every day (hours, minutes) [27]. The variable was dichotomized into being an active commuter "yes" or "no", with a cut-off value of 4 minute spent on active commuting per day and meeting recommended levels of physical activity (≥ 30 minutes) per day "yes" or "no".

2.2.2 Objective measures of access to public transportation

The objective measures of access to public transportation were determined by combining the geographical location of the home address of each participant in the study population, road networks from the Danish Geodata agency and the geographic location of transit stops and their service level. Network distances from each respondent's home address to the nearest stop (bus, metro, s-train, train) and to all stops within 1 km walking and 3 km cycling distance were calculated using origin–

destination matrices in the Network Analyst application of ESRI ArcGIS 10.1. (Redlands, CA: Environmental Systems Research Institute).

2.2.3 Distance to and density of public transportation stops

The access to public transportation was constructed as distance and density measures. The distance to the nearest bus stop and train station was treated both as a continuous and a categorical variable. The distance to metro or S-train was not linearly related to the outcome and was therefore not treated as continuous measures. The categorisation of the distance to the nearest bus stop was chosen to reflect the distances people are willing to walk to a bus stop that are often used in the literature (400 and 800 metres) [28]. As 76.6% of the respondents resided within 400m of a bus stop, it was decided to categorise respondents into residing right next to a bus stop (0 – 200m), residing within immediate walking distance (200 - 400m), residing within a long walking distance (400 - 800m) and having a long distance to a bus stop (> 800m). The other transport modes had much lower access coverage so the categorization was determined by living at a closer or further location for walking distance (0–500m and 501–1000 m), cycling distance (1001–3000 m) and more than 3000 m from a station. The categorical distances for the train, S-train and metro was inspired by a travel survey performed in the Capital Region of Denmark in 2006 -2007 [29], showing that the mean walking and cycling distance for any purpose was 1 km walking and 3 km cycling. Density of bus stops was defined as the number of bus stops within 1 km walking distance from the home address. The density was divided into 4 categories based on the density distribution: 0–5, 6–10, 11–15 and >15 stops. As an alternative density measure, an index of transport modes reachable within 1 km and 3 km network distance from home address was created. The index with values from 0 to 4 was defined as:

$$TMI = BUS(0,1) + Metro(0,1) + S\text{-}Train(0,1) + Train(0,1)$$

No stop within 1 km for each mode was taken to equal 0, and 1 if a stop was present.

2.2.4 Service level of public transportation

Distinct active bus routes at the nearest bus stop and service frequency (number of departures) at the nearest and the "best" stop was extracted from www.Rejseplanen.dk. The time period covered were the morning rush hour (7:00 a.m. to 8:00 a.m.). The "best" connected stop was defined as the stop with the highest service frequency within 1 km walking distance from the individual home address. In addition to the distance density measures, a measure of unique bus routes reachable within 1 km walking distance was created. Distinct bus routes at the nearest stop were divided into 3 categories and unique bus routes within 1 km walking distance and the frequency of services was divided into 4 categories based on the distribution of data. Inspired by Kamada et al. [19], two bus convenience measures were created combining the distance and service frequency at the nearest stop and distance and service frequency at the "best" connected stop, as shown in Table 1.

Table 1. Categorization of the bus convenience based on bus frequency and distance to a bus stop with 4 indicating the highest bus convenience.

	Bus frequency			
Distance to bus stop	High	Medium-high	Medium-low	Low
Close	4	4	3	2
Medium close	4	4	3	2
Medium far	3	3	1	1
Far	2	2	1	1

2.2.5 Socio-demographic covariates

The individual socio-demographic covariates were register-based age, gender and education level. Four classes of education level were defined: primary or secondary school, vocational education, bachelor degree or equivalent, and master's or PhD degree.

2.2.6 Contextual covariates

Median income level, population density and street connectivity were grouped by parishes, the smallest administrative units in Denmark. Median income level and population were based on individual data from central registers. Street connectivity was defined by the gamma index $\gamma = l/(3(n - 2)$, where n equals the intersections [30].

2.2.7 Statistical analyses

Prior to running the analyses, a pair-wise correlation matrix was constructed to identify variables that were highly correlated. Highly correlated variables were defined as having a Pearson's correlation coefficient of > 0.55 [13]. The results were used to evaluate the risk of multicollinearity in the multilevel models. We used SAS version 9.3 (SAS Institute, Inc., Cary, North Carolina) to perform the multilevel regression analyses (GLIMMIX procedure) to investigate which of the access to public transportation measures was associated with being an active commuter and meeting recommended levels of physical activity. A two-level model was fitted with individuals (level 1, n = 28,928) nested within parishes (Level 2, n = 223).

Two empty models (active commuter and meeting recommendations of physical activity) were estimated to detect whether there was a contextual dimension to 1) being an active commuter and to 2) meeting recommended levels of physical activity. The contextual dimension was estimated by calculating the Intra Class Correlation Coefficient (ICC). A 3-step modeling strategy was used and the ICC was calculated for each model: (1) the primary determinant was included in the model; (2) the individual level covariates were included to examine whether the between-parishes variance was attributable to a compositional effect. Individual age, gender and education was included in all of the models; (3) the parish level contextual covariates were included to see if the remaining between-parish variance could be explained by contextual factors. Furthermore to see if the associations differed among subgroups, it was examined if there was a significant interaction with distance to work or study expressed by having commute distances of ≤ 5 km, 5 to 10 km, 10 – 20 km and ≥ 20 km, with age defined by three groups (16-29, 30-45, 46-64 years) and gender. Values of $p < 0.05$ were considered statistically significant. If an interaction was present, the odds of being an active commuter when belonging to a given distance or age category were calculated based on the full model.

3. Results and Discussion

3.1 Results

3.1.1 Demographics and public transportation access

Of the study population, 72.9% reported active commuting each day and 50.6% met recommended levels of physical activity (moderate intensity physical activity) from active commuting alone (Table 2). Respondents with a vocational education had the lowest proportion of active commuters (63.5%). Women had a higher proportion of active commuters than men and the proportion of active commuters decreased with increasing commute distance and age.

Table 2. Descriptive statistics of study population demographics and distances to work by subgroups of active commuters (> 4min/day) (yes/no) and meeting recommendations of physical activity (yes/no).

	Total	**Active commuter (> 4min/day)**		**Meeting recommended levels of physical activity (≥ 30min/day)**	
	N (%)	**Yes** N (%)	**No** N (%)	**Yes** N (%)	**No** N (%)
Total population	28,928 (100)	21,094 (72.9)	7834 (27.1)	14,629 (50.6)	14,299 (49.4)
Age[a]	40.9 (13.1)	39.7 (13.5)	44.3 (11.2)	39.3 (13.7)	42.6 (12.2)
Age groups (6 missing)					
16 - 29 years	6538 (22.6)	5724 (87.5)	814 (12.5)	4245 (64.9)	2293 (35.1)
30 - 45 years	10,782 (37.3)	7507 (69.6)	3275 (30.4)	5056 (46.9)	5726 (53.1)
46 - 64 years	11,604 (40.1)	7860 (67.7)	3744 (32.3)	5327 (45.9)	6277 (54.1)
Gender (6 missing)					
Male	12,624 (43.6)	8518 (67.5)	4106 (32.5)	5709 (45.2)	6915 (54.8)
Female	16,300 (56.3)	12,573 (77.1)	3727 (22.9)	8919 (54.7)	7381 (45.3)
Education (438 missing)					
Primary or secondary school	8150 (28.2)	6434 (78.9)	1716 (21.1)	4608 (56.5)	3542 (43.5)
Vocational education	7742 (26.8)	4920 (63.5)	2822 (36.5)	3273 (42.3)	4469 (57.7)
Academy or bachelor degree	7898 (27.3)	5822 (73.7)	2076 (26.3)	3992 (50.5)	3906 (49.5)
Master or PhD degree	4723 (16.3)	3593 (76.1)	1130 (23.9)	2501 (53.0)	2222 (47.0)
Commute distance					
≤ 5 km	9237 (31.9)	7957 (86.1)	1280 (13.9)	5731 (62.0)	3506 (38.0)
5 - 10 km	6676 (23.1)	5117 (76.6)	1559 (23.4)	3995 (59.8)	2681 (40.2)
10 - 20 km	6516 (22.5)	4265 (65.5)	2251 (34.5)	2730 (41.9)	3786 (58.1)
> 20 km	6499 (22.5)	3755 (57.8)	2744 (42.2)	2173 (33.4)	4326 (66.6)

[a] Age is expressed by mean and standard deviation

The mean commute distance was 14.6 km (SD = 15.9), see table 3. Active commuters reported shorter commute distances (12.7 km) than non-active commuters (19.6 km). Mean individual distance to the nearest bus stop was 300 meters, whereas the mean distance to train and S-train was approximately 4 km and 13.3 km to the nearest metro stop. Active commuters had on average shorter mean distances to nearest train, s-train and metro stop than non-active commuters.

Table 3. Distance to the different public transportation modes in the population by subgroups of of active commuters (> 4min/day) (yes/no) and meeting recommendations of physical activity (yes/no).

	Total	**Active commuting (> 4min/day)**		**Meeting recommended levels of physical activity (≥ 30min/day)**	
		Yes	**No**	**Yes**	**No**
Km	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Distance to work or education	14.6 (15.9)	12.7 (14.8)	19.6 (17.6)	11.8 (14.0)	17.1 (17.2)
Distance to a bus stop	0.3 (0.2)	0.3 (0.2)	0.4 (0.3)	0.3 (0.2)	0.3 (0.3)
Distance to a train station	4.2 (3.5)	4.0 (3.3)	4.8 (4.0)	3.8 (3.1)	4.6 (3.8)
Distance to a S-train station	4.1 (5.8)	3.7 (5.4)	5.3 (6.6)	3.3 (5.0)	5.0 (6.4)
Distance to a metro stop	13.3 (14.2)	11.6 (13.3)	17.9 (15.5)	10.1 (12.4)	16.6 (15.1)

3.1.2 Association between distance to public transportation and active commuting

The unadjusted models showed that distance to nearest bus stop or train station was negatively associated with being an active commuter (Table 4). After adjusting for potential confounders, greater distance to a bus stop and a train station was associated with significantly lower odds of being an active commuter as well as with meeting recommended levels of physical activity. Residing > 400 meters from a bus stop was associated with significantly lower odds of being an active commuter compared to residing within 400 meters, and residing > 800 meters from a bus stop was associated with significantly lower odds of being an active commuter compared to residing within 800 meters. For trains, S-trains and metro there was a similar dose-response trend, as greater distance to a station was associated with lower odds of being an active commuter. For trains and S-trains, there was only a significant difference in the association for those residing > 3 kilometres from a train or S-train station compared to residing within 500 metres. The adjusted models for meeting recommendations of physical activity showed that for trains, metro and S-trains, there was only a significant difference in the association for those residing > 3 kilometres compared to residing within 500 metres.

Table 4. Crude and adjusted associations (OR) between objective distance measures to public transportation and being an active commuter and meeting recommended levels of physical activity. Between neighbourhood variation is expressed by Intra-class correlation coefficient (ICC). Significant associations are highlighted in bold text.

	Active commuter (> 4min/day)		**Meeting recommended levels of physical activity (≥ 30min/day)**	
	Model 1: Crude	**Model 3: Fully adjusted model**	**Model 1: Crude**	**Model 3: Fully adjusted model**
	OR (CI)	OR (CI)[b]	OR (CI)	OR (CI)[b]
Distance to bus stop (km)	**0.71 (0.63 - 0.80)**	**0.76 (0.67 - 0.85)**	**0.8 (0.71 - 0.90)**	**0.86 (0.76 - 0.96)**
P-value[a]	*<0.0001*	*<0.0001*	*0.0002*	*0.0099*
ICC	*12.6*	*2.1*	*11.9*	*2.1*
Distance to bus stop (m)				
Close (≤ 200)	1.00	1.00	1.00	1.00
Moderate Close (201 - 400)	1.00 (0.94 - 1.07)	1.02 (0.95 - 1.09)	1.01 (0.95 - 1.07)	1.02 (0.96 - 1.08)
Moderate Far(401 - 800)	**0.88 (0.82 - 0.96)**	**0.92 (0.85 - 1.00)**	0.94 (0.87 - 1.01)	0.98 (0.91 - 1.05)
Far (>800)	**0.68 (0.58 - 0.80)**	**0.73 (0.62 - 0.86)**	**0.75 (0.63 - 0.88)**	**0.79 (0.67 - 0.94)**
P-value[a]	*<0.0001*	*<0.0001*	*0.0010*	*0.0183*
ICC	*12.8*	*2.1*	*12.0*	*2.1*
Distance to train station (km)	**0.93 (0.91 - 0.94)**	**0.97 (0.96 - 0.98)**	**0.94 (0.93 - 0.96)**	**0.98 (0.97 - 0.99)**
P-value[a]	*<.0.0001*	*<.0.0001*	*<0.0001*	*0.001*
ICC	*11.3*	*2.1*	*10.9*	*2.1*
Distance to train station (m)				
Close (0 - 500)	1.00	1.00	1.00	1.00
Medium Close (501 - 1000)	0.92 (0.76 - 1.12)	0.97 (0.79 - 1.18)	1.08 (0.90 - 1.29)	1.13 (0.95 - 1.35)
Medium Far (1001 - 3000)	0.84 (0.69 - 1.02)	0.86 (0.71 - 1.03)	1.03 (0.87 - 1.23)	1.06 (0.90 - 1.26)
Far (>3000)	**0.65 (0.52 - 0.80)**	**0.75 (0.62 - 0.91)**	0.88 (0.72 - 1.07)	0.99 (0.83 - 1.18)
P-value[a]	*<0.0001*	*0.0002*	*0.0101*	*0.1254*
ICC	*12.8*	*2.1*	*12.2*	*2.1*
Distance to S-train station (m)				
Close (0 - 500)	1.00	1.00	1.00	1.00
Medium Close (501 - 1000)	0.99 (0.87 - 1.12)	1.03 (0.90 - 1.17)	1.02 (0.91 - 1.13)	1.03 (0.93 - 1.15)
Medium Far (1001 - 3000)	**0.79 (0.70 - 0.90)**	0.89 (0.78 - 1.00)	0.90 (0.80 - 1.00)	0.96 (0.86 - 1.07)
Far (>3000)	**0.53 (0.44 - 0.62)**	**0.81 (0.69 - 0.94)**	**0.64 (0.55 - 0.75)**	**0.87 (0.76 - 1.00)**
P-value[a]	*<0.0001*	*0.0002*	*0.0017*	*0.0260*
ICC	*9.6*	*2.0*	*9.3*	*1.9*
Distance to metro stop (m)				
Close (0 - 500)	1.00	1.00	1.00	1.00
Medium Close (501 - 1000)	0.83 (0.66 - 1.04)	0.86 (0.68 - 1.08)	1.03 (0.87 - 1.21)	1.04 (0.88 - 1.22)
Medium Far (1001 - 3000)	**0.66 (0.52 - 0.84)**	**0.78 (0.63 - 0.98)**	0.93 (0.77 - 1.12)	1.05 (0.89 - 1.24)
Far (>3000)	**0.27 (0.21 - 0.35)**	**0.56 (0.45 - 0.71)**	**0.42 (0.35 - 0.51)**	**0.74 (0.61 - 0.88)**
P-value[a]	*<0.0001*	*<0.0001*	*0.0017*	*<0.0001*
ICC	*5.2*	*1.6*	*5.8*	*1.7*

[a]P-value from type III test of the association.
[b]All models adjusted for neighbourhood confounders population density, median income, street connectivity and individual confounders. Bus distance adjusted for age, gender, education, bus routes and bus frequency. Train, S-train and metro adjusted for age, gender, education and distance to bus.

3.1.3 Association between density and service of public transportation and active commuting

The categorised density and service measures and their association with active commuting are shown in Table 5 and 6. For the adjusted models, density of bus stops, bus routes within 1 km and number of transport modes within walking and cycling distance were all positively associated with being an active commuter.

Table 5. Crude and adjusted associations (OR) between objective density measures of public transportation and being an active commuter and meeting recommended levels of physical activity. Between neighbourhood variation is expressed by Intra-class correlation coefficient (ICC). Significant associations are highlighted in bold text.

	Active commuter (> 4min/day)		**Meeting recommended levels of physical activity (≥ 30min/day)**	
	Model 1: Crude	**Model 3: Fully adjusted model**	**Model 1: Crude**	**Model 3: Fully adjusted model**
	OR (CI)	OR (CI)[b]	OR (CI)	OR (CI)[b]
Density of bus stops				
Low (0 - 5)	1.00	1.00	1.00	1.00
Medium low (6 - 10)	**1.29 (1.20 - 1.39)**	**1.25 (1.16 - 1.34)**	**1.19 (1.11 - 1.28)**	**1.16 (1.08 - 1.25)**
Medium high (11 - 15)	**1.56 (1.42 - 1.71)**	**1.32 (1.20 - 1.45)**	**1.38 (1.26 - 1.51)**	**1.22 (1.12 - 1.34)**
High (>15)	**2.42 (2.12 - 2.76)**	**1.52 (1.32 - 1.75)**	**1.64 (1.46 - 1.85)**	**1.22 (1.08 - 1.38)**
P-value[a]	*<.0.0001*	*<.0.0001*	*<0.0001*	*<0.0001*
ICC	*6.4*	*1.8*	*8.4*	*1.9*
Bus routes at stops within 1 km				
Low (0-2)	1.00	1.00	1.00	1.00
Medium low (3-4)	**1.17 (1.08 - 1.26)**	**1.14 (1.05 - 1.23)**	**1.10 (1.02 - 1.19)**	**1.09 (1.01 - 1.17)**
Medium High(5-6)	**1.49 (1.34 - 1.65)**	**1.27 (1.14 - 1.41)**	**1.30 (1.18 - 1.43)**	**1.18 (1.07 - 1.29)**
High (>6)	**1.75 (1.56 - 1.96)**	**1.31 (1.16 - 1.48)**	**1.32 (1.19 - 1.46)**	1.09 (0.98 - 1.22)
P-value[a]	*<.0.0001*	*<.0.0001*	*<0.0001*	*0.0082*
ICC	*8.1*	*1.8*	*9.8*	*2.0*
TMI 1 km				
0[c]	**0.67 (0.53 - 0.83)**	**0.67 (0.54 - 0.85)**	**0.77 (0.60 - 0.98)**	**0.78 (0.61 - 0.99)**
1	1.00	1.00	1.00	1.00
2	**1.29 (1.20 - 1.40)**	**1.19 (1.11 - 1.29)**	**1.18 (1.10 - 1.27)**	**1.12 (1.04 - 1.19)**
3	**1.53 (1.30 - 1.79)**	**1.35 (1.16 - 1.56)**	**1.14 (1.00 - 1.30)**	1.07 (0.94 - 1.20)
P-value[a]	*<.0.0001*	*<.0.0001*	*<0.0001*	*0.0018*
ICC	*10.7*	*1.9*	*11.1*	*2.0*
TMI 3 km				
1 [c]	1.00	1.00	1.00	1.00
2	**1.35 (1.21 - 1.51)**	**1.19 (1.07 - 1.33)**	**1.29 (1.15 - 1.45)**	**1.16 (1.04 - 1.29)**
3	**1.85 (1.61 - 2.12)**	**1.42 (1.24 - 1.62)**	**1.70 (1.49 - 1.95)**	**1.38 (1.21 - 1.57)**
4	**4.30 (3.57 - 5.18)**	**1.87 (1.53 - 2.28)**	**2.79 (2.35 - 3.31)**	**1.44 (1.21 - 1.71)**
P-value[a]	*<.0.0001*	*<.0.0001*	*<0.0001*	*<0.0001*
ICC	*4.9*	*1.7*	*6.0*	*1.7*

[a]P-value from type III test of the association.
[b]All models adjusted for neighbourhood confounders population density, median income, street connectivity. Bus distance adjusted for individual confounders age, gender, education, bus routes and bus frequency. Train, S-train and metro adjusted for individual confounders age, gender, education and distance to bus.
[c]The number represents number of transport modes within walking(1 km) and cycling distance (3 km).

No significant associations were found between bus service measures at the nearest stop (routes and service frequency) and being an active commuter. A higher bus convenience (combined distance with service frequency) at the nearest stop was associated with significantly higher odds of being an active commuter except for the medium-low category. No significant association was found between the bus convenience at the "best" stop and being an active commuter. In the adjusted models for meeting recommended levels of physical activity, density of bus stops, the bus frequency at the "best" stop and transport modes within cycling distance were positively associated with meeting recommendation of physical activity. Unique bus routes and transport modes within walking distance showed a positive trend but having a high number of bus routes and three transport modes were not significantly associated with higher odds of meeting the recommendations of physical activity. No significant association was found between bus services at the nearest stop or bus convenience and meeting recommended levels of physical activity.

Table 6. Crude and adjusted associations (OR) between objective measures of public transportation services and being an active commuter and meeting recommended levels of physical activity. Between neighbourhood variation is expressed by Intra-class correlation coefficient (ICC). Significant associations are highlighted in bold text.

	Active commuter (> 4min/day)		**Meeting recommended levels of physical activity (≥ 30min/day)**	
	Model 1: Crude	**Model 3: Fully adjusted model**	**Model 1: Crude**	**Model 3: Fully adjusted model**
	OR (CI)	OR (CI)	OR (CI)	OR (CI)
Bus routes at nearest stop				
Low (≤ 1)	1.00	1.00	1.00	1.00
Medium (2)	1.00 (0.93 - 1.07)	0.98 (0.91 - 1.05)	1.00 (0.93 - 1.06)	1.00 (0.93 - 1.07)
High (>2)	1.03 (0.95 - 1.12)	0.97 (0.88 - 1.07)	0.94 (0.87 - 1.01)	0.92 (0.84 - 1.01)
P-value[a]	*0.7272*	*0.7919*	*0.1362*	*0.1372*
ICC	*13.7*	*2.0*	*12.7*	*2.1*
Frequency of bus service at nearest stop				
Low (0-2)	1.00	1.00	1.00	1.00
Medium-low (3 - 6)	**0.90 (0.83 - 0.98)**	0.92 (0.85 - 1.01)	**0.91 (0.84 - 0.99)**	0.95 (0.88 - 1.03)
Medium-high (7 - 15)	1.02 (0.93 - 1.12)	1.00 (0.91 - 1.11)	0.98 (0.90 - 1.06)	1.00 (0.92 - 1.09)
High (> 15)	1.07 (0.96 - 1.18)	0.96 (0.84 - 1.08)	0.98 (0.90 - 1.07)	0.99 (0.89 - 1.10)
P-valu[a]*e*	*0.0008*	*0.1148*	*0.1142*	*0.5287*
ICC	*12.6*	*2.1*	*12.3*	*2.1*
Frequency of bus services at "best stop"				
Low (<= 10)	1.00	1.00	1.00	1.00
Medium low (11 - 20)	**1.21 (1.10 - 1.32)**	1.09 (0.99 - 1.19)	**1.19 (1.09 - 1.30)**	**1.10 (1.01 - 1.19)**
Medium high (21 - 40)	**1.43 (1.30 - 1.57)**	**1.15 (1.04 - 1.26)**	**1.37 (1.25 - 1.50)**	**1.16 (1.06 - 1.27)**
High (> 40)	**1.99 (1.77 - 2.24)**	**1.26 (1.11 - 1.43)**	**1.62 (1.46 - 1.81)**	**1.18 (1.05 - 1.32)**
P-value[a]	*<0.0001*	*<.0.0001*	*<0.0001*	0.0142
ICC	*7.2*	*1.6*	*8.0*	*1.8*
Bus convenience at nearest stop				
Low (1)	1.00	1.00	1.00	1.00
Medium-low (2)	**1.17 (1.06 - 1.29)**	**1.12 (1.01 - 1.25)**	**1.15 (1.04 - 1.27)**	1.10 (1.00 - 1.21)
Medium-high (3)	1.07 (0.98 - 1.16)	1.06 (0.97 - 1.15)	1.05 (0.97 - 1.14)	1.05 (0.97 - 1.41)
High (4)	**1.30 (1.19 - 1.43)**	**1.19 (1.08 - 1.32)**	**1.15 (1.05 - 1.25)**	**1.10 (1.00 - 1.21)**
P-value[a]	*<0.0001*	*0.0016*	0.0042	0.1591
ICC	*11.7*	*2.1*	*12.7*	*2.1*
Bus convenience at "best" stop				
Low (1)	1.00	1.00	1.00	1.00
Medium-low (2)	1.05 (0.98 - 1.13)	1.01 (0.94 - 1.08)	1.01 (0.95 - 1.09)	0.98 (0.91 - 1.05)
Medium-high (3)	**1.19 (1.10 - 1.29)**	1.08 (1.00 - 1.17)	**1.13 (1.05 - 1.22)**	**1.07 (0.99 - 1.15)**
High (4)	**1.28 (1.12 - 1.47)**	1.14 (0.99 - 1.32)	**1.10 (0.99 - 1.23)**	**1.06 (0.94 - 1.19)**
P-value[a]	*<0.0001*	*0.1175*	0.0021	0.0857
ICC	*12.3*	*2.0*	*11.8*	*2.1*

[a]P-value from type III test of the association.
[b] All models adjusted for neighbourhood confounders population density, median income, street connectivity. Bus routes at nearest stop adjusted for individual confounders distance to nearest bus stop, bus frequency at nearest stop, age, gender and

education. Bus frequency at nearest bus stop adjusted for individual confounders distance to nearest bus stop, bus routes at nearest stop, age, gender, education. Bus convenience at nearest stop adjusted for individual confounders bus routes at nearest stop, age, gender and education. Bus frequency at "best" stop and Bus convenience at "best" stop adjusted for individual confounders density of bus stops within 1 km, age, gender and education.

The ICC in the two empty models showed a noticeable significant between-neighbourhood variation of 13.6% in being an active commuter and 12.7 % in meeting recommendations of physical activity. The ICC in the unadjusted models varied from 5.3 to 12.7 % and was significantly reduced to between 1.6 and 2.1% in the fully adjusted models.

3.1.4 Subgroup analysis

For respondents with commute distance ≤ 10 km, increasing density of bus stops, bus routes within 1 km, frequency of bus services at "best" stop, bus convenience at the nearest stop and TMI at 1 km and 3 km were all positively associated with significantly higher odds of being an active commuter. Furthermore, there was a trend for bus convenience at the "best" stop to be related to active commuting. For respondents with commute distances > 10 km the associations were insignificant to a large extent. For meeting recommendations of physical activity, the subgroup analysis showed a strong positive association between all density measures and ≥ 30 minutes of active commuting per day for those with commute distances of 5 – 10km. In those having ≤ 5km commute distance, there was a positive trend between the density measures and ≥ 30 minutes of active commuting per day. For commute distances > 10 km the associations was insignificant.

For women, distance to public transportation was associated with lower odds of being an active commuter and higher density was associated with higher odds of being an active commuter. For men, the associations were insignificant to a large extent and with no clear trend. Only transport modes accessible within 3 km showed a trend towards increasing number of transport modes being associated with significantly higher odds of being an active commuter. The associations for women attenuated in the models of meeting recommended levels of physical activity but remained significant.

For the age group between 30 and 45 the significant associations found in the adjusted models remained. These associations were significant but less pronounced in the age group between 46 and 64. For the age group between 16 and 29, the associations were insignificant to a large extent and with no clear trend for both being an active commuter as well as meeting recommendations of physical activity.

3.2 Discussion

The findings of the present study suggest that being an active commuter is influenced by the proximity to public transportation, number of bus routes, bus service frequency and accessible transport modes within walking or cycling distance. Public transportation characteristics that facilitate active commuting are thus complex and need to be better modeled and described than by distance measures alone.

This study highlights the importance of considering not only the nearest stop but also alternative services to describe access to public transportation. While no significant association was found for number of routes and service frequency at the nearest stop, positive associations were found between bus service frequency and being an active commuter at the "best" stop. This suggests two very different conclusions about the association between public transportation and active commuting. In urban or suburban areas the "best" stop might be located close to the nearest stop; therefore, it is important to include other stops than nearest stop in measures of local public transportation facilities. Having access to more transport mode choices than a bus within walking or cycling distance also had a positive effect on being an active commuter. One explanation for the non-significant associations with the nearest stop might be that the variation in the measures at the nearest stop is too low to reveal an association. The association with the bus frequency has only been investigated in relation to active commuting in few other studies [13;19;31]. Dalton et al. [13] found that medium (tertiles) and low bus frequencies were significantly associated with lower odds of using public transportation compared to having a high frequency. Kamada et al. [19] did not find a significant association, but their sample size was small and therefore had very low statistical power

In accordance with other studies [13;16-19], negative associations were found between the distance to the nearest stop or station and being an active commuter as well as with meeting recommendations of physical activity. The results suggests that shorter walking distances to a bus stop supports active commuting, whereas the attractiveness of the other public transportation modes (metro, trains and s-trains) diminishes slower with access distance. This is in line with other studies showing that people will walk further to trains than to busses [28;31]. Due to the large study area many respondents have very long distances to the train, S-train and metro stations. This clearly attenuates the associations for these three transport modes. Locally, the three transport modes are very important for commuting by public transportation in the region with direct and fast services to the main city centres.

The positive associations found between the different density measures and being an active commuter is supported by other studies findings [20;22-24]. The alternative density measures, the unique bus routes within 1 km and number of transport modes measures the effect of having additional services within walking distance and show strong associations with active commuting. The outcomes for the density measures reveal the importance of both easy access to public transportation and to different transport modes and routes that enable more destinations to be reached. The positive associations found may not only reflect a higher use of public transportation in areas of high density, but also better connected street networks that allow more direct travelling and the presence of cycle lanes that facilitate active commuting.

In the present study, having a high frequency and a short distance to the nearest stop are associated with significantly higher odds of being active compared to having longer distances and low frequency. This was not significant for the "best" stop convenience measure or in association to meeting the recommendations of physical activity. Kamada et al. [19] did not find a significant association between their convenience measure and active commuting, but their results showed the same positive trend that higher convenience was associated with higher odds of active commuting. It is highly questionable, however, whether the two studies are comparable as Kamada et al. [19] investigated women living in a rural setting in Unnan City, Japan, with a generally low public transportation service level.

The finding of a significant interaction with commute distance is in line with previously presented results; indicating, that distance to work is a strong predictor of travel mode choice when commuting [13;15]. When the commuting distance is > 10 km the number of commuters who cycle all the way to work decreases markedly and car-based commuting becomes dominant [32]. This is also evident from the results of this study. For those residing within 10 km from work or study, the associations between the objective measures and active commuting are more pronounced than for those having ≤ 5 km commuting distance. This relationship changes when looking at meeting the recommendations of physical activity where those having a commuting distance between 5 and 10 km show more pronounced associations. The longer distances may explain this shift where those travelling further spent more time on active transportation. Altogether, the associations that were found reflect the attractiveness of public transportation as a travel mode when it is easy to access and enables multiple destinations to be reached. Car-based commuting is likely to be the main reason why the associations were weaker for the respondents residing far (> 10km) from work or study.

Women's commute travel choices seem to be more influenced by access to public transportation than men. The associations found in the full model remain significant and in the same magnitude for women, but for men these associations become insignificant. Men's travel choice may be more influenced by car ownership. However, data on car ownership were not available in the present study.

The 16 to 29 year olds are to a large extent walking or cycling in combination with using public transportation which may explain the non-significant associations between the access measures and being an active commuter in this age group. The travel choice in the 30 to 45 year old group seems to be much more influenced by access to public transportation and a higher access and service level result in higher odds of being an active commuter and meeting recommended levels of physical activity. The associations become less pronounced for the 46 to 64 year olds. This may be the result of more car-based commuting and possibly also caused by less cycling or walking due to functional decline with age.

3.2.1 Strengths and limitations

This study has several strengths. The individual GIS-based objective measures for distance from home address to public transportation, calculated using network analysis and the inclusion of transport service characteristics, provided a sound setting for studying the association between access to public transportation and active commuting. The study tested a wide range of objective density measures and the inclusion of the "best" stop in the analysis enabled a discussion to take place about how well conclusions based on nearest stop capture the significance of public transportation to active commuting. The large study population selected from one of the largest health surveys in the world and the individual register-based socioeconomic data provide a unique study base. Estimates of the ICC showed a clear amount of variation between the neighbourhoods on the outcome variable. The neighbourhood effect was accounted for in the 3-step multilevel model and significant reduction in the variation among neighbourhoods was observed.

The main limitation of the study is that the self-reported daily active commuting may be subject to information bias. Respondents might have reported daily active commuting even though they had only taken the bus a few times a month, which would have made the share of active commuters too high. The survey is cross-sectional in design so it is not possible to conclude on causality. The active commuting information is restricted to time spent walking or cycling to work or study, and it does not refer to time spent in usage of public transportation or car. This restricts the analysis to looking at active commuting and not the individual choice of travel mode. Whether the services at nearest or "best" stop was able to transport the respondents to work or study is unknown. The high proportion of respondents reporting active commuting in this study (72.9 %) is substantially higher than in other studies. Results may therefore not be generalizable to other countries or cities where active commuting is not as common. However, the observed associations are quite similar to other studies, which indicate that the findings may be comparable. A number of confounders identified in other studies were not included in this study. Car ownership is often a strong predictor in analyses of travel mode choice [33]. It was not included in this study as it was not the aim to investigate how car ownership affects active commuting. Health measures such as general health state, disability and chronic diseases may affect travel choice and it would be good to include those in further analyses.

4. Conclusions

The results of the study show that easy access to public transportation and high frequency transport services have the potential to promote active commuting. The results suggest that active commuting is influenced by the proximity and density of public transportation stops; however, transport service characteristics such as number of routes, service frequency and accessible transport modes within walking or cycling distance are also important factors associated with active commuting by public transportation. Future research should include public transportation service characteristics at all stops within walking distance and it should incorporate travel choices to gain a better understanding of the driving forces behind active commuting. Commute distance is seen to be limiting active commuting. Provision of more direct routes from rural or suburban districts to main centres may facilitate residents to use public transportation rather than car-based commuting.

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Author Contributions

SD, HSH, MA and CH designed the protocol for this study. SD performed the GIS and statistical analysis and drafted the manuscript. HSH, MA and CH critically revised and helped to draft the manuscript. All authors read and approved the final manuscript.

Conflicts of Interest

The Authors declares that there is no conflict of interest

References

1. MacDonald JM, Stokes RJ, Cohen DA, Kofner A, Ridgeway GK. The effect of light rail transit on body mass index and physical activity. Am J Prev Med **2010** Aug;39(2):105-12.
2. Wen LM, Rissel C. Inverse associations between cycling to work, public transport, and overweight and obesity: findings from a population based study in Australia. Prev Med **2008** Jan;46(1):29-32.
3. Hamer M, Chida Y. Active commuting and cardiovascular risk: a meta-analytic review. Prev Med **2008** Jan;46(1):9-13.
4. Laverty AA, Mindell JS, Webb EA, Millett C. Active travel to work and cardiovascular risk factors in the United kingdom. Am J Prev Med **2013** Sep;45(3):282-8.
5. Warburton DE, Charlesworth S, Ivey A, Nettlefold L, Bredin SS. A systematic review of the evidence for Canada's Physical Activity Guidelines for Adults. Int J Behav Nutr Phys Act **2010**;7:39.
6. Pratt M, Sarmiento OL, Montes F, Ogilvie D, Marcus BH, Perez LG, et al. The implications of megatrends in information and communication technology and transportation for changes in global physical activity. Lancet **2012** Jul 21;380(9838):282-93.
7. WHO. Global recommendations on physical activity for health. Geneva: World Health Organisation . 2010.
8. Villanueva K, Giles-Corti B, McCormack G. Achieving 10,000 steps: a comparison of public transport users and drivers in a university setting. Prev Med **2008** Sep;47(3):338-41.
9. Wener R., Evans G. A morning stroll: Levels of physical activity in car and mass transit commuting. Environment and Behaviour **2007**;39:62-74.
10. Lachapelle U, Frank L, Saelens BE, Sallis JF, Conway TL. Commuting by public transit and physical activity: where you live, where you work, and how you get there. J Phys Act Health **2011** Jan;8 Suppl 1:S72-S82.
11. Sahlqvist S, Song Y, Ogilvie D. Is active travel associated with greater physical activity? The contribution of commuting and non-commuting active travel to total physical activity in adults. Prev Med **2012** Sep;55(3):206-11.
12. Adams EJ, Goodman A, Sahlqvist S, Bull FC, Ogilvie D. Correlates of walking and cycling for transport and recreation: factor structure, reliability and behavioural associations of the perceptions of the environment in the neighbourhood scale (PENS). Int J Behav Nutr Phys Act **2013**;10:87.
13. Dalton AM, Jones AP, Panter JR, Ogilvie D. Neighbourhood, Route and Workplace-Related Environmental Characteristics Predict Adults' Mode of Travel to Work. PLoS One **2013**;8(6):e67575.
14. Winters M, Brauer M, Setton EM, Teschke K. Built environment influences on healthy transportation choices: bicycling versus driving. J Urban Health **2010** Dec;87(6):969-93.
15. Badland HM, Oliver M, Kearns RA, Mavoa S, Witten K, Duncan MJ, et al. Association of neighbourhood residence and preferences with the built environment, work-related travel behaviours, and health implications for employed adults: findings from the URBAN study. Soc Sci Med **2012** Oct;75(8):1469-76.
16. Boarnet M.G., Greenwald M., McMillan T.E. Walking, urban design, and health. Journal of Planning Education and Research **2008**;27:341-58.

17. Coogan PF, White LF, Adler TJ, Hathaway KM, Palmer JR, Rosenberg L. Prospective study of urban form and physical activity in the Black Women's Health Study. Am J Epidemiol **2009** Nov 1;170(9):1105-17.
18. Frank LD, Greenwald MJ, Winkelman S, Chapman J, Kavage S. Carbonless footprints: promoting health and climate stabilization through active transportation. Prev Med **2010** Jan;50 Suppl 1:S99-105.
19. Kamada M, Kitayuguchi J, Inoue S, Kamioka H, Mutoh Y, Shiwaku K. Environmental correlates of physical activity in driving and non-driving rural Japanese women. Prev Med **2009** Dec;49(6):490-6.
20. Badland H., Hickey S., Bull F., Giles-Corti B. Public transport access and availability in the RESIDE study: is it taking us where we want to go? Journal of Transport & Health **2013**;1:45-9.
21. Hino AA, Reis RS, Sarmiento OL, Parra DC, Brownson RC. Built Environment and Physical Activity for Transportation in Adults from Curitiba, Brazil. J Urban Health **2013** Oct 5.
22. Li F, Harmer PA, Cardinal BJ, Bosworth M, Acock A, Johnson-Shelton D, et al. Built environment, adiposity, and physical activity in adults aged 50-75. Am J Prev Med **2008** Jul;35(1):38-46.
23. Lovasi GS, Neckerman KM, Quinn JW, Weiss CC, Rundle A. Effect of individual or neighborhood disadvantage on the association between neighborhood walkability and body mass index. Am J Public Health **2009** Feb;99(2):279-84.
24. McConville ME, Rodriguez DA, Clifton K, Cho G, Fleischhacker S. Disaggregate land uses and walking. Am J Prev Med **2011** Jan;40(1):25-32.
25. Stone J., Mees P. Planning public transport networks in the post-petroleum era. Australien Planner 2010;47:263-71.
26. Christensen AI, Ekholm O, Glumer C, Andreasen AH, Hvidberg MF, Kristensen PL, et al. The Danish National Health Survey 2010. Study design and respondent characteristics. Scand J Public Health **2012** Jun;40(4):391-7.
27. Andersen LG, Groenvold M, Jorgensen T, Aadahl M. Construct validity of a revised Physical Activity Scale and testing by cognitive interviewing. Scand J Public Health **2010** Nov;38(7):707-14.
28. El-Geneidy A, Grimsrud M, Wasfi R, Tétreault P, Surprenant-Legault J. New evidence on walking distances to transit stops: Identifying redundancies and gaps using variable service areas. Transportation **2014**;41(1):193-210.
29. Region Hovedstaden. Transportvaner i hovedstadsregionen. Hvad fortæller den nationale Transportvane Undersøgelse (TU)? (in danish). 2009. Report No.: version 2.0.
30. Berrigan D, Pickle LW, Dill J. Associations between street connectivity and active transportation. Int J Health Geogr **2010**;9:20.
31. Wasfi RA, Ross NA, El-Geneidy AM. Achieving recommended daily physical activity levels through commuting by public transportation: unpacking individual and contextual influences. Health Place **2013** Sep;23:18-25.
32. DTU. The Danish National Travel Survey. http://www.modelcenter.transport.www6.sitecore.dtu.dk/english/TU/Hovedresultater. 2013.
33. Ref Type: Online Source

34. Eluru N, Chakour V, El-Geneidy AM. Travel mode choice and transit route choice behaviour in Montreal: insights from McGill university members commute patterns. Public Transp **2012**;4(2):129-49.

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Building a multimodal network and determining individual accessibility by public transportation (in review, Environment and Planning B). Submitted September 2013, revised manuscript submitted July 2014.

Building a multimodal network and determining individual accessibility by public transportation

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BUILDING A MULTIMODAL NETWORK AND DETERMINING INDIVIDUAL ACCESSIBILITY BY PUBLIC TRANSPORTATION

Abstract

The increased availability of transit schedules from web sites or travel planners as well as more disaggregate data has led to a growing interest in creating individual public transportation accessibility measures. However, used extensively, standard GIS software do not have direct capabilities to integrate transit schedules into multimodal networks and measure space-time based accessibility. This has caused authors to either simplify travel time elements or develop tools to overcome these challenges. This paper aims at describing and implementing a method that enables integrating time table data from a travel planner into a multimodal network modal using simple SQL programming and standard GIS. The method presented here integrates all parts of travelling with public transportation from individual home addresses to all reachable transit stops within different travel time thresholds. The method is successfully used to create a multimodal travel time network model of the Capital Region of Denmark comprising bus, train, light rail, metro, ferry as well as integrating walking or cycling to stops. Here, the individual accessibility is defined as accessibility areas. The accessibility areas are created at morning rush-hour for a study population of 29,447 individuals and a few examples of accessibility areas are presented. The results show a big difference in individual public transportation accessibility in the region. In addition, how the transit network is accessed, whether it is at the nearest stop or at all stops within 1 kilometre walking distance or 3 kilometre cycling distance, leads to very different accessibility areas.

1 Introduction

Faced with a growing urban population the challenges of traffic congestion and corresponding air pollution are persistently drawing the attention towards public transportation as a more sustainable solution compared to car-based commuting. In addition, from a public health perspective, commuting by public transportation provides more health benefits than car-based commuting as a consequence of more regular physical activity when walking to stops, transfers and end locations (Pratt et al., 2012). Accordingly, theories of travel behaviour and related mode choice studies have been of interest to transport and urban planners for a long time. Besides looking at the individual and neighbourhood factors, studies have focused on how transport networks (road network or public transportation) support people in reaching their destinations such as jobs (Shen, 1998; Kwok and Yeh, 2004; Hess, 2005; Kawabata and Shen, 2006; Kawabata, 2009; Benenson et al., 2011) or health care (Higgs, 2005; Martin et al., 2008, Peipens et al., 2011) expressed by accessibility measures.

A substantial amount of accessibility measures has been developed over time mainly due to different purpose of analysis, data availability and aggregation level. Four main categories of accessibility measures have been identified and described in a number of reviews: opportunity based, gravity type, utility based and space-time accessibility measures (Handy and Niedermeier, 1999; Geurs and van Wee, 2004; Liu and Zhu, 2004; Lei and church, 2010). Recently there has been a growing interest in creating individual based public transportation accessibility measures using multimodal network analysis (Tribby and Zandbergen, 2011). This is driven not only by the demand for sustainable solutions but also through an increased availability of more disaggregate data such as parcel-level data, available transit schedules from web sites or travel planners, together with high performing GIS software. The individual approach seems logical, since ridership decision is based on the individual's personal criteria such as the cost, distance, access and services provided (Lei and Church, 2010; Eluru et al., 2012; Pratt and Evans, 2004). Moreover, the public transit accessibility measures seek to integrate the temporal differences in services during the day (rush-hour, off-peak). This follows the theory of the space-time accessibility measures, in which activities are influenced by the individual's needs and the time of day (Hägerstrand, 1970).

Measuring the public transportation accessibility is based on solving a multimodal network problem with time as constraint. Studies use GIS extensively to solve the multimodal network analysis and some studies have constructed GIS tools to measure and visualize public transportation accessibility. Both Liu and Zhu (2004) and O'Sullivan et al. (2000) developed GIS applications to automatically create isochrones of areas accessible within a given travel time from an origin. The resulting catchment areas can easily be combined with other data to create different accessibility measures. Benenson et al. (2011) and Lei and Church (2010) has created applications integrated in ArcGIS (ESRI) which can measure accessibility as a service or an access area in Tel Aviv and Santa Barbara, US. Furthermore, Martin et al. (2008) created a software tool to analyse bus travel times based on the UK ATCO standard text files and measure the access to health care in Devon and Cornwall.

The standard ArcGIS are used in a number of studies to calculate public transportation accessibility (Salonen and Toivonen, 2013; Tribby and Zandbergen, 2011; Mavoa et al., 2012) whereas Gent and Symonds (2004) use the software Accession to calculate catchment areas. Standard GIS software does not have capabilities to handle the temporal variation in transit services directly, so average travel times based on routes are necessarily applied to the links between the stops. Salonen and Toivonen (2013) create three models of accessibility. In the first two models they use ArcGIS to calculate the accessibility with the same simplifications of the temporal variation in services as the studies above. In their third “advanced” model, they use the API of the local travel planner (Helsinki, Finland) and calculate the accessibility based on the official up-to-date public transport schedules. Walking to a transit stop and from a transit stop to a destination is integrated in the travel planner. Although the model is called advanced it only involves a tool like a web-crawler to extract the data from the travel planner.

1.1 Aims of the study

Following the limitations introduced when managing temporal transit tables in network analysis in a standard GIS, the aim of this methodological paper is to propose a method that integrate the temporal component from a public transit time table into a multimodal transport network model using only simple programming. Secondly, using a door-to-door approach as described by Benenson et al. (2011) and Salonen and Toivonen (2013), the aim is to incorporate all parts of travelling with public transportation and determine individual based public transportation accessibility area during morning rush-hour for a large study population. We have addressed these aims by creating a multimodal model that integrate a travel planner into a weighted directed graph together with walking trips calculated in a GIS. Travel time is the main input to calculating the accessibility. A short review of how the individual public transport accessibility measures described above integrates travel time in their calculations is given here.

2 Accessibility: Travel time in the multimodal public transportation network

Public transportation accessibility measures are linked directly to how the different temporal elements of a trip are integrated. A trip to work can be divided into; 1) accessing the transit network by walking or cycling to a stop; 2) waiting for the departure of a service at the initial stop or transfers 3) in-vehicle transport time 4) making interchanges or transfer between modes and finally 5) exiting the vehicle and walk or bike to the final destination (egress). Some studies integrate detailed transit schedule information in their analysis (Benenson et al., 2011; Lei and Church, 2010; Salonen and Toivonen, 2013; Tribby and Zandbergen, 2012; Mavoa et al., 2012; Martin et al., 2008) while others rely on average travel speeds assigned to the whole route (Liu and Zhu, 2004; O’Sullivan et al., 2000; Peipens et al., 2011). How travel time is handled in the different studies is eloborated in this section.

1) A large number of researchers use 400 meters as the distance people are willing to walk to a bus stop, whereas the distance is 800 meters for train stations (Badland et al., 2013; El-Geneidy et al.

2009; Dalton et al., 2013; McConville et al., 2011). An increased distance to a transit has been found to be associated with lower odds for walking for transportation (McConville et al., 2011) and lower odds for public transportation use (Dalton et al., 2013). Krygsman et al. (2004) signifies that the access and egress stages of a transit trip are the weakest part of a multimodal public transport chain. An increase in the distance results in a decrease in the use of public transportation due to the time spent on walking relative to the in-vehicle time.

Although proximity is a key element in travelling by public transit network, only Benenson et al. (2011) specifies a maximum access distance of 300 m crow-fly (Euclidean) distance. The other studies either ignore or integrate the access time regardless of the distance. This may be due to the fact that the access distance to transit stops in urban areas is never large. O'Sullivan et al. (2000), Lei And Church (2010) and Salonen and Toivonen (2013) take into account accessing at other stops than the nearest, since the nearest stop might not provide the timeliest connection to a given destination.

2) The wait time at the initial stop or when transferring is in most studies simplified to one half of the headway time (time interval between departures) (O'Sullivan et al., 2000; Tribby and Zandbergen, 2012; Gent & Symonds, 2004), whereas Mavoa et al. (2012) used 10 minutes and Peipens et al. (2011) used 16 minutes as the bus wait time and 6 minutes for the trains. In urban areas, having services with high service frequency, this simplification is not creating large errors. In rural areas with low service frequency it is on the other hand underestimating the accessibility by ignoring that people may choose to enter the stop just in time to depart. In other studies, the wait time is calculated from the transit schedules (Benenson et al., 2011; Lei and Church, 2010; Salonen and Toivonen, 2013).

3) When schedules are not integrated, the standard procedure used for calculating in-vehicle travel time is to use the average travelling speed calculated from time spent on the whole route divided by the route length (Liu and Zhu, 2004; O'Sullivan et al., 2000). Tribby and Zandbergen (2012) simplify the travel time between the stops (route segment) by averaging the time for the individual busses between 7 and 9 a.m.

4) Transfers between modes are often ignored (Liu and Zhu, 2004) or handled in the same way as wait time (frequency of service) (O'Sullivan et al., 2000; Mavoa et al., 2012). A study from the Netherlands by De Jonge and Teunter (2013) showed that integrating walk transfers into the

multimodal network reduced total travel time so this is an important feature of travelling. Using transit schedules enables calculation of transfer time as the elapsed time between arrival and the departure of a new service. Which transfer connections that are allowed in the network needs to be decided. O'Sullivan et al. (2000) allowed transfers between bus and train when buffer zones applied to their routes crossed. Benenson et al. (2011) allows walk transfers of 500 meter crow-fly distance and Gent and Symonds allow 1 km walk transfers.

5) Only Benenson et al. (2011) sets a limit to the egress walk from the last transit stop (300 crow-fly distance). Accessibility measures are often limited to a certain travel time threshold such as 30 or 60 minutes, and the egress is thus limited by that time threshold. This ignores the fact that people are not willing to walk long distances from last stop to their destination.

3. Methodology

3.1 Study area and data

The study area is The Capital Region of Denmark. The Region covers 2,561 km2 (1,973 km2 without the island Bornholm) with the main urban areas, the Copenhagen metropolitan area (1,181,239 inh.) and 7 smaller cities (20 – 50,000 inh.). Figure 1 show the Capital Region of Denmark and bordering countries Sweden to the Northeast and Germany to the south. The study population for which we create individual measures are participants from the cross-sectional Danish National Health Survey 2010 (Christensen et al, 2012). The population selected in this study is 16-64 year old inhabitants working or in education living in the Capital Region of Denmark. The participants from the island Bornholm is excluded due to the isolation from the metropolitan area and public transport network. Excluding the Island Bornholm and restricting the commute distance to work to less than 200 kilometres, result in a population size of 29,447 participants. Home addresses for each participant were geo-coded using address matching to the official address register from the Danish Geodata Agency. All Danish addresses with UTM coordinates are freely available from www.kortforsyningen.dk.

FIGURE 1 HERE!

A road network was obtained from the Danish Geodata Agency's KORT 10 geodatabase. The geodatabase contains thematic data on different road classes, land use features, cadastre, buildings and cultural features in a geometric resolution of 1:10,000. Data were captured in February 2010 which matches the period of the health survey questionnaire. Roads not suited for walking (motorways) is removed before analyses of walking distances.

Public transportation timetable data are obtained from the travel planner Rejseplanen.dk (www.rejseplanen.dk) which is the official travel search engine for all public transportation in Denmark. Data is extracted from the database and received in HAFAS text-file format. The text-files are stored in a SQL based database. The data contains useful information on transport mode, operators, geographical location of transit stops, transit lines, time of operation, time schedules etc. The time tables cover the period from February to April 2010 which matches the health survey questionnaire. There are five groups of public transport modes in the study area; train (international, regional and local), bus (international, regional and local), S-train, metro and ferry. The S-train is a rapid urban and suburban train service serving the Copenhagen metropolitan and suburban areas having 84 stations and about 170 km double tracks. The metro is located in the Copenhagen city center having 2 lines with 22 stations (9 underground) and 20.5 km tracks in 2010. The public transportation in the region is dominated by "The Fingerplan", a strategic urban development plan from 1947 stating that the Copenhagen metropolitan area was to develop along six fingers centred along the S-train network (Knowles, 2012). This plan has created a gap in train based transportation between the fingers which is covered by busses; see also figure 5.

The transit time tables, walkable road network and the individual addresses represent the base data for creating the multimodal public transport network. The study area borders Sweden by a bridge and ferries to the east and Region Zealand to the west and south. In order to minimise edge effects, public transportation and road network in the Zealand Region where included so that the individual accessibility area can grow beyond the region boundary. An exception is in Sweden where all connections to Sweden are cut at the final stop or road exit in Denmark. This is due to lack of data on public transportation in Sweden.

3.2 Constructing the multimodal Public transport network

The proposed multimodal network model is conceptually a weighted directed graph having time as the link weight and only allowing one-way traffic (Bang-Jensen et al, 2008). The two-dimensional design is controlled by time restricting topology rules. There are a number of ways to construct the network model. The standard GIS network models are usually two-dimensional, but it is possible to use three-dimensional topology in ArcGIS 10.1 having time as the third axis. We choose a simple two-dimensional for the multimodal network since at least initially we want to be independent of GIS software.

The different components of transit travel time (in-vehicle, interchange, transfer, wait, and egress time) as described in section 2, are constructed in the SQL database environment using simple programming. In addition to the transit time tables, access walk/bike time to initial stop as well as transfer walk distances are calculated in a GIS environment and integrated in the SQL database. The construction of the different travel parts (time) in the multimodal network is illustrated in Figure 2 and described below.

3.2.1 Walking or cycling

Walking and cycling to initial transit stop and transfer walks between stops are determined by origin-destination (O-D) matrices in ArcGIS 10.1. The O-D matrix tool uses Dijkstra's algorithm (Dijkstra, 1959) to find the shortest path between origin A and destination B. Similar types of GIS software can be used to perform this calculation. The access distance to all public transit stops is calculated as network distance from all geo-coded home addresses (29,447) (origins) to all accessible transit stops. The access walking distance is set to a maximum of 1 kilometre and the access bike distance is set to a maximum of 3 kilometres. The maximum walk distance chosen is larger than access distances often used in other studies, see section 2. It is based on results from the Danish National Travel Survey performed in 2006 – 2007, were the average walking distance for any purpose was 1 kilometre and cycling for any purpose was 3 kilometres in the Capital Region of Denmark. The survey was based on 17,299 trips conducted by 4,833 persons.

The transfer walks between transit stops are similarly calculated by O-D matrices using 1 km network distance as the maximum distance between the stops. The maximum transfer distance corresponds to the distance used by Gent and Symonds (2004). The transfer walk lines are calculated between all 5 public transit modes (bus, train, S-train, metro and ferry). Walk links between stops with the same transit mode such as a bus stop to bus stop is calculated if existing bus routes do not include both stops.

The access walk and bike distances as well as the transfer walk distances are transformed into time using 5 km/h as walking speed and 15 km/h as cycling speed. Given the maximum distances described above, the maximum access time walking or cycling to a stop equals 12 minutes.

3.2.2 Constructing the multimodal network

The multimodal public transport network containing bus, metro, train, s-train and ferry lines, is, as mentioned, created in a SQL database environment. First we minimise the dataset to only contain routes active during morning rush-hour on a Monday between 07:15 and 08:15, as we are only interested in possible trips with a duration of up to 1 hour. Secondly the in-vehicle time between stops are calculated for all unique routes and for each transport mode. All routes are restricted as one-way routes by adding a cost of 80 minutes (> 60 minutes) to the opposite direction of the vehicle direction. To simplify the public transportation network, the routes in the network are not 'true' routes. The bus routes do not follow the road network but are instead straight lines between stops with time-table based in-vehicle time on each segment.

The initial access walk or cycle links are integrated into the multimodal network by creating access links to the accessible stops within 1 kilometre walking and 3 kilometres cycling distance. In some areas participants will have the same walk or bike access time to the same stop although having different home addresses. This will result in the same accessibility measure. Only unique access time links are used so instead of using links between the original home address locations and transit stops, a new location close to the transit stops is added and a link created having the access time + wait time for a service as weight. This result in 11,085 access walk links, instead of 29,447 home address to transit links. The initial walk or bike access travel time and wait time for a service at the initial stop is restricted to 20 minutes, see Figure 2. The 20 minutes limit is allowing flexible travel. Most commuters are optimising there trip to work by arriving just in time for the bus or train. Choosing a start time of 07:15, we are not able to capture this just in time optimisation. The 20 minutes take into account a maximum access time and a tolerable wait time between 8 and 20 minutes.

The challenge having different routes arriving and departing at the same stop and allowing interchanges is solved by splitting a given transit stop into as many stops as the number of unique routes entering the station (all directions). We have conducted this by adding a number (1, 2, 3…) to every route entering the stop and offsetting the original x or y coordinates by the number times 3 meters, see Figure 3. Instead of having one entry point we now have as many entry points (stops) as the number of unique routes arriving and departing at a specific stop. Benenson et al. (2011) uses a similar approach although they do not specifically describe how this is conducted.

FIGURE 3 HERE!!

Arriving at a stop on a route enables a number of interchanges to other routes leaving at the stops just created, see Figure 3. The interchanges are constructed as line segments between the new stops and the cost of making the interchanges is calculated as the difference between the arrival time of a service and the departure time of a new service. The interchange time is restricted to a maximum of 20 minutes which reduces the number of interchange links in the network markedly (Figure 3).

The transfer walk links are integrated into the multimodal network. The time table is used to check the departure time of a service at a stop. If it is accessible within 20 minutes of the arrival time of a service linked to that stop by a transfer link, a transfer can be conducted. Figure 4 show a combination of having both the interchange possibilities from Figure 3 and now including possible walk connections between a bus stop and a train station. Walk transfers are only constructed where arrivals and departures are no more than 20 minutes apart. Given a distance of 12 minutes walking (1 km), the maximum wait time at the new stop is 8 minutes. The walk link weight equals the time difference between arrival and departure.

FIGURE 4 HERE!

The egress walk time is calculated as the time left to walk away from a stop when arriving. The time left is restricted by a threshold time (30, 45 or 60 minutes) or a maximum distance of 1 kilometre equal to 12 minutes walking. This is used to restrict the size of each egress area in line with the definition of the initial access distance. The Egress walk areas are computationally calculated as service areas around the transit stops and are based on the same road network as were used to calculate the walk trips in the multimodal network.

The multimodal network is lastly built as a network data set in a GIS and the accessibility measures are ready to be calculated. The network is reduced by cutting away transit stops that are too far away (> 1 hour travel time) from the boundary of the Capital Region of Denmark to enhance performance. The reduced network contains 627,113 lines and 55,493 nodes.

3.3 Accessibility area

The individual public transportation accessibility area within 30, 45 and 60 minutes is calculated using the constructed multimodal public transportation network. The thresholds are used in many accessibility analyses and they provide a measure of both local (30 minutes) and regional accessibility (60 minutes). Following the approach from O'Sullivan et al. (2000), Lei And Church (2010) and Salonen and Toivonen (2013) accessing at other stops than the nearest is included to find the timeliest connection to a given location (stop).

3.3.1 Individual travel time

The accessibility areas are based on individual travel time from home address to destinations in the multimodal network (stops). The travel time for public transportation t_{pt} from an origin to a destination is defined as:

$$t_{pt} = t_{ac} + t_v + t_i + t_{tr} \quad (1)$$

t_{ac} is the access time spend on walking or cycling to initial stop plus the wait time at the initial stop. t_v is the in-vehicle time or motorised travel time. It is the sum of the travel time spent in modes of public transportation on a given trip e.g. 5 minutes in a bus and 25 min on a train. t_i is the sum of interchange time and is a composite of the time spent on interchanges (wait time for a new connection) and t_{tr} is time spend on transfers (walking) to other stops plus wait time for a service at the new stops. As described previously, we allow walk transfers between stops that are up to 1 kilometre apart (12 minutes).

The egress time at a destination is determined by the travel time t_{pt} spent at a destination and the travel time thresholds (30, 45 and 60 minutes). If we use 30 minutes as travel time threshold, the egress time left for walking at a destination with t_{pt} = 24 minutes equals 6 minutes or 500 meters of walking. The egress time is calculated from t_{pt} after the analyses have been run in the multimodal network.

3.3.2 Measure of Individual Accessibility: Accessibility area

We define three measures of individual accessibility by public transportation as the accessibility area using services at nearest stop, all stops within 1 kilometre of walking from home address (density based) and all stops within 3 kilometres of cycling from home address. The access area is calculated as:

$$AAo = Aac + Aegr \quad (2)$$

AAo is the accessibility area for a given origin o, Aac is the initial access area resulting from network distances of 1 kilometre walking or 3 kilometres cycling in all directions from home address. Aegr is the sum of egress areas resulting from walking from all reachable stops (destinations in the multimodal network) in all directions with a distance that equals the time left when arriving at the destination or a maximum of 12 minutes walking. It is not allowed to exit the vehicle between stops so the individual access area is the sum of the areas that can be covered walking from reachable transit stops. We only allow walking from destinations not cycling. This is mainly because in 2010 it was not allowed to bring bicycles into other transportation modes but S-trains during rush hour. The access (egress) areas are dissolved at individual level (unique ID) resulting in 3 accessibility measures per individual in the study population also further divided into the time thresholds 30, 45 and 60 minutes. The accessibility areas can be easily combined with other data such as jobs and other opportunities to make comparable location based analyses. This is though beyond the scope of this paper.

3. Results

The constructed multimodal network with straight lines between connected stops is shown in Figure 5. A visual inspection of the network reveals the important city centres in the Region and in the bordering Region Zealand. As we move towards the rural zone the number of different public transportation modes as well as number of routes decline as would be expected. The "Finger Plan" is evident in the S-train lines with 6 fingers all meeting at the Central Station in Copenhagen and is further connected by a ring around the metropolitan area. Only one ferry line is included in the network at the northwest corner of the region.

FIGURE 5 HERE!

For each individual three measures has been created: 1) access area using services at the nearest stop 2) access area calculated from all access areas of all stops within a walking distance of 1 km and 3) access area calculated from all access areas of all stops within 3 km cycling distance. The areas have been dissolved by individual id such that no area overlap exists. Figure 6a show all the possible routes that can be travelled within 60 minutes by an individual living in the suburban zone next to an S-train and a train station. Due to the new stop design the same station can be reached a large number of times. To find the fastest route, it is necessary to select the minimum travel time at each stop/station from the resulting OD matrix. It is evident that the train and S-train routes are fast routes with few stops creating long lines away from Copenhagen.

FIGURE 6a-d HERE!

Figure 6b show the resulting accessibility area from travelling in the rural part of the region with poor access to public transportation. The nearest stop is 6 minutes walking distance from home address but do not have any services between 07:15 and 07:35. There are 5 stops within 1 kilometre walking distance, but only one transit stop (the local train station) have services operating between 07:15 and 07:35. This stop is a 9 minute walk away from home address and the departure is at 07:30, giving a start access + wait time of 15 minutes. Cycling 3 kilometres away from the home address does not provide access to other stops. The resulting access area is small and centred around the local train network. The rather long start access + wait time result in a rapidly growing accessibility area when travelling 45 and especially 60 minutes as oppose to 30 minutes.

Figure 6c and 6d shows the resulting accessibility area for an individual living right next to the busiest bus, train, S-train and metro station in Copenhagen, Norreport station. The accessibility area shown, result from using services at nearest stop/station or all stops within 1 km of walking within the three travel time thresholds (30, 45 and 60 minutes). The accessibility area is only slightly bigger (35 km^2) when using the density based (stops within 1 kilometre) approach instead of the nearest stop. This is because the nearest stop is well-connected to all transport modes and walking to other stops does not provide better services.

Table 1. Average individual public transportation accessibility areas and range in km^2 resulting from using services at nearest stop, stops within 1 km walking distance and stops within 3 km cycling distance in Copenhagen city area, suburban and city areas outside Copenhagen and rural areas in the Capital Region of Denmark at 07:15 on a Monday morning in march 2010.

	Copenhagen city area (km² /range km²)	**Suburban and city areas** (km² /range km²)	**Rural area** (km² /range km²)
Nearest stop			
30 min	64.8 (0-209.2)	23.7 (0 - 181.1)	6.5 (0-65.3)
45 min	250.8 (0-500.2)	117.4 (0 - 449.4)	27.0 (0-332.6)
60 min	424.6 (0-695.0)	251.4 (0 - 647.6)	77.3 (0-518.3)
1 km walking distance			
30 min	95.4 (0-235.8)	37.4 (0-191.7)	8.9 (0-68.6)
45 min	334.7 (0-510.8)	167.6 (0-454.7)	36.3 (0-332.7)
60 min	538.9 (0-695.1)	332.2 (0-650.8)	99.4 (0-518.4)
3 km cycling distance			
30 min	143.1 (16.7-235.9)	73.2 (0-192.8)	18.6 (0-100.3)

45 min	407.6 (122.1-510.9)	246.5 (0-473.0)	58.0 (0-353.5)
60 min	607.6 (324.7-713.3)	427.4 (0-671.0)	139.1 (0-522.0)

Table 1 shows the average accessibility area for individuals living in the Copenhagen city area, the suburban area and cities outside Copenhagen as well as in the rural areas. Living in the Copenhagen city area with well-connected public transportation leads to a large accessibility area. It is worth noting that even in Copenhagen, some individuals living in the harbour area do not have access to any services within walking distance during rush-hour. The density based access to the transit network (1 km and 3 km) result in much larger accessibility areas than when only accessing at the nearest stop. This support that the nearest stop not always provide the timeliest connections and therefore other stops need to be taken into account in these measures. The time thresholds used also shows that 30 minutes travel time is sensitive to the time it takes to access the transit network. The 30 minute accessibility areas are thus much smaller than the 45 and 60 minutes accessibility areas.

4. Discussion

The present study proposes a method for constructing a multimodal network of public transportation from a travel planner using only light programming in SQL. The two-dimensional approach is chosen because we want to make the network as simple as possible and to some extent be software independent. Implementing all transport modes available into the model as well as access walk links and transfer walk links between stops is easily constructed by integrating walk time with the transit time tables. Splitting transit stops into a stop per service enables interchanges, transfers between services as well as handling wait time in accordance with the time table. The design thereby overcome some of the challenges of using a standard GIS, such as using half the headway time as wait and transfer time. The model is thus suitable for modelling individual public transportation accessibility integrating travel planner data. Another benefit of the simple two-dimensional approach is that it enables other GIS software than ArcGIS to perform the O-D matrix calculations.

The access to the public transit network is achieved by walking or cycling to transit up to 3 kilometres away. In Denmark it is very common to bike to an S-train, train or large bus stop, which is why we include stops within 3 km of cycling, although this has not been used in other studies. Network distance is used as oppose to the crow-fly distance used by Benenson et al. (2011). In rural areas with only a few roads, the difference between the two distance measures can be quite large and network distance is widely accepted as a better measure of walking/cycling distance. The other studies of public transportation accessibility do not describe how the access distance is taken into account, although they describe that the access time included in the travel time. Whether access is limited by distance or time is not known. In line with O'Sullivan et al. (2000), Lei and Church (2010) and Salonen and Toivonen (2013) we include accessing other stops than the nearest stop in order to capture the timeliest connections. The rather large difference between accessibility area size resulting from entering only the nearest stop and when including all stops within 1 kilometre walking (Table 1), highlight the importance of including access to other than the nearest stop in these measures.

Following the models of Benenson et al. (2011), O'Sullivan et al. (2000) and Gent & Symonds (2004), transfer walk links are integrated into the multimodal model. Including transfer links is believed by the authors to better illustrate the flexible travel experience commuters are faced with when travelling. Many of the earlier studies only include bus as travel mode and walk links are not as important as in the case of having many transport modes available. Lei and Church (2010) identifies the shortest elapsed time for transfers based on the time schedule, but how this is implemented in their model is fully described. Salonen and Toivonen (2013) uses the travel planner to model travel time. Interchanges and transfers are handled by the travel planner and this means relying on the walking speed and distances agreed upon by transport authorities. Using the API method certainly overcome many of the challenges of building temporal enabled multimodal networks in GIS, but the researchers do not have a lot of options to change the parameters of the travel planner.

The egress time and accessibility area calculated in this study is inspired by Benenson et al., (2011). As with the access time, egress time is limited to 12 minutes walking or time left within a given travel time threshold. This also follows the findings of Krygsman (2004) that egress time is important for the travel experience and is limiting travelling with public transportation if egress distances are too large. The other studies presented in section 2 do not explicitly describe if the egress time is limited by time or distance.

One of the strengths of the proposed model is that it enables modelling accessibility from a door-to-door approach including all parts of the trip. Some of the earlier challenges of using average speed as in-vehicle time between stops (Liu and Zhu, 2004; O'Sullivan et al., 2000) and wait time as half the headway time (O'Sullivan et al., 2000; Tribby and Zandbergen, 2012; Gent & Symonds, 2004) or a fixed time (Mavoa et al., 2012; Peipens et al., 2011) is overcome by integrating the transit time table. Furthermore interchanges and transfers are handled by creating multiple stops from the original stop. This overcomes the challenges of using standard GIS network models where the temporal variable needs to be simplified (Tribby and Zandbergen, 2012).

In the present study the accessibility area is defined in the same way as the access area used by Benenson et al. (2010). All stops up to 3 km distance from home are included in the analysis in order to cover cycling trips to stops. In the presented results, the accessibility area increases when using all stops within 1 kilometre walking distance and 3 kilometre cycling distance as oppose to service at the nearest stop. This is to be expected because more timely connections are reachable when looking beyond the nearest stop. Analysis of the transport mode at the nearest can reveal the sensitivity to accessibility of living next to a train station or a bus stop. The rural example shows that some areas in the study area are quite remote in terms of public transportation.

Some limitations need to be mentioned. One of the limitations of the two-dimensional approach is that it creates a large number of nodes and edges due to splitting the stops and incorporating walk lines. We were specifically interested in the morning rush hour and thereby reduced the network quite substantially and the computation performance in ArcGIS network analyst is high and acceptable. If larger time windows are to be used, a performance test should be carried out. The method does rely on some knowledge of SQL programming. The more complex the network, the more connections need to be constructed. The model initially covered all of Denmark and was reduced due to performance enhancement. This shows that the method is flexible and that it is possible to handle quite large amounts of time table data and built a multimodal travel time network using this method.

A few limitations come from the used data. The multimodal network relies on the travel planner time schedule and do not take traffic congestion or service level into account. This can cause the calculated access areas to be too large. Many larger roads in the metropolitan area have designated bus lanes which reduce the impact from traffic congestion. The weather plays a role in the service level in Denmark where occasional snowy or icy conditions can slow down or close the public transportation for shorter periods. Furthermore, we have no data on how well the public transportation has performed in the period covered. The results show what can be achieved if the services run 100 % on schedule. The overall impact of these issues on the access area is though estimated to be low.

5. Conclusion

With an increasing interest in individual public transportation accessibility and more time table and disaggregate data becoming available, methods need to enable integration of space-time data. The proposed method in this research demonstrates that it is possible to integrate travel time data into a multimodal network using only simple programming. Splitting the original transit stops into unique route-based stops enables interchanges, transfers and wait-time integration according to the time table data. This overcome some of the main problems, when measuring accessibility using a standard GIS. Including access and transfer walk links from O-D matrices shows that the method is flexible and more services can be incorporated. The individual approach used provides knowledge about the individual ability to reach other destinations and opportunities. However, the different access approach to the transit network (nearest stop or density) resulted in quite different accessibility areas. These issues are important to take into account in future studies.

References

Bang-Jensen J, Gutin G, 2008, “Digraphs: Theory, Algorithms and Applications”, 2nd Edition, Springer

Benenson I, Martens K, Rofé Y, Kwartler A, 2010, “Public Transport versus private car GIS-based estimation of accessibility applied to the Tel Aviv metropolitan area”. The Annals of Regional Science 47 (3) 499-515

Christensen AI, Ekholm O, Glümer C, Andreasen AH, Hvidberg MF, Kristensen PL, Larsen FB, Ortiz B, Juel K, 2012, “The Danish National Health Survey 2010. Study design and respondent characteristics”. Scandinavian Journal of Public Health 40 (4) 391-397

de Jonge B, Teunter RH. Optimizing itineraries in public transportation with walks between rides. Transportation Research Part B: Methodological 2013;55:212-26.

Dijkstra E W, 1959, “A Note on Two Problems in Connexion with Graphs”. Numerische Mathematik 1 269 - 271

Eluru N, Chakour V, El-Geneidy A M, 2012, “Travel mode choice and transit route choic behaviour in Montreal: insights from McGill university members commute patterns”

Gent C, Symonds G. Advances in public transportation accessibility assessments for development control - a proposed methodology. PTRC AnnualTransport Practitioners' Meeting, UK, 2005.

Geurs K T, van Wee B, 2004, “Accessibility evaluation of land-use and transport strategies: review and research directions”. Journal of Transport Geography 12 127-140

Handy S L, Niemeier D A, 1997, “Measuring accessibility: an exploration of issues and alternatives” Environment and Planning A 29 1175-94.

Hägerstrand T, 1970, “What about people in regional science”? Papers of the Regional Science Association 24 7-21

Hess D B, 2005, “Access to Employment for Adults in Poverty in the Buffalo-Niagara Region”. Urban Studies 42 (7) 1177-1200

Higgs G, 2005, “A literature review of the use of GIS-based measures of access to health care services”. Health Services and Outcomes Research Methodology 5 119 - 139

Kawabata M, 2009, “Spatiotemporal dimensions of modal accessibility disparity in Boston and San Fransisco”. Environment and Planning A 41 183-198

Kawabata M, Shen Q, 2006, “Job accessibility as an indicator of auto-oriented urban structure: a comparison of Boston and Los Angeles with Tokyo”, Environment and Planning B: Planning and Design 33 115-130

Knowles R, 2012, "Transit oriented development in Copenhagen, Denmark: from the finger plan to Ørestad". Journal of transport Geography 22 251–261

Kwok R C, Yeh A G O, 2004, “The use of modal accessibility gap as an indicator for sustainable transport development”. Environment and Planning A 36 921-936

Lei T L, Church R L, 2010, “Mapping transit-based access: integrating GIS, routes and schedules”. International Journal of Geographical Information Science 24 2 283-304

Liu S, Zhu X, 2004, “Accessibility Analyst: an integrated GIS tool for accessibility analysis in urban transportation planning”. Environment and Planning B: Planning and Design 31 105-124

Martin D, Jordan H, Roderick P, 2008, “Taking the bus: incorporating public transport timetable data into health care accessibility modelling”. Environment and Planning A 40 2510 – 2525

Mavoa S, Witen K, McCreanor T, O’Sullivan D, 2012, “GIS based destination accessibility via public transit and walking in Auckland, New Zealand”. Journal of Transport Geography 20 15-22

McConville M E, Rodriguez D A, Clifton K, Cho G, Fleischhacker S, 2011, “Disaggregate land uses and walking”. American Journal of Preventive Medicine 40 25-32

O’Sullivan D, Morrison A, Shearer J, 2000, “Using desktop GIS for the investigation of accessibility by public transport: an isochrone approach”. International Journal of Geographical Information Science 14 1 85-104

Peipens L A, Graham S, Young R, Lewis B, Foster S, Flanagan B, Dent A, 2011, “Time and Distance Barriers to Mammography Facilities in the Atlanta Metropolitan Area”. Journal of Community and Health 36 675-683

Pratt M, Sarmiento OL, Montes F, Ogilvie D, Marcus BH, Perez LG, et al. The implications of megatrends in information and communication technology and transportation for changes in global physical activity. Lancet 2012 Jul 21;380(9838):282-93

Pratt R H, Evans J E, 2004, “Bus routing and coverage”. TCRP Report 95: traveler reponse to transportation system changes. Transportation Research Board, Washington, DC.

Region Hovedstaden, 2009, Transportvaner i Region Hovedstaden (in Danish), (Transport habits in The Capital Region of Denmark), http://www.regionh.dk/NR/rdonlyres/AECCBC70-3A59-4964-962F-EAC02224F1FA/0/Transportvanerihovedstadsregionen.pdf

Salonen M, Toivonen T, 2013, “Modelling travel time in urban networks: comparable measures for private car and public transport” Journal of Transport Geography 31 143-153

Shen Q, 1998, “Location characteristics of inner-city neighbourhoods and employment accessibility of low-wage workers”. Environment and Planning B: Planning and Design 25 (3) 345-365

Tribby C P, Zandbergen P A, 2012, “High-resolution spatio-temporal modeling of public transit accessibility”. Applied Geography 34 345-355

Figure captions:

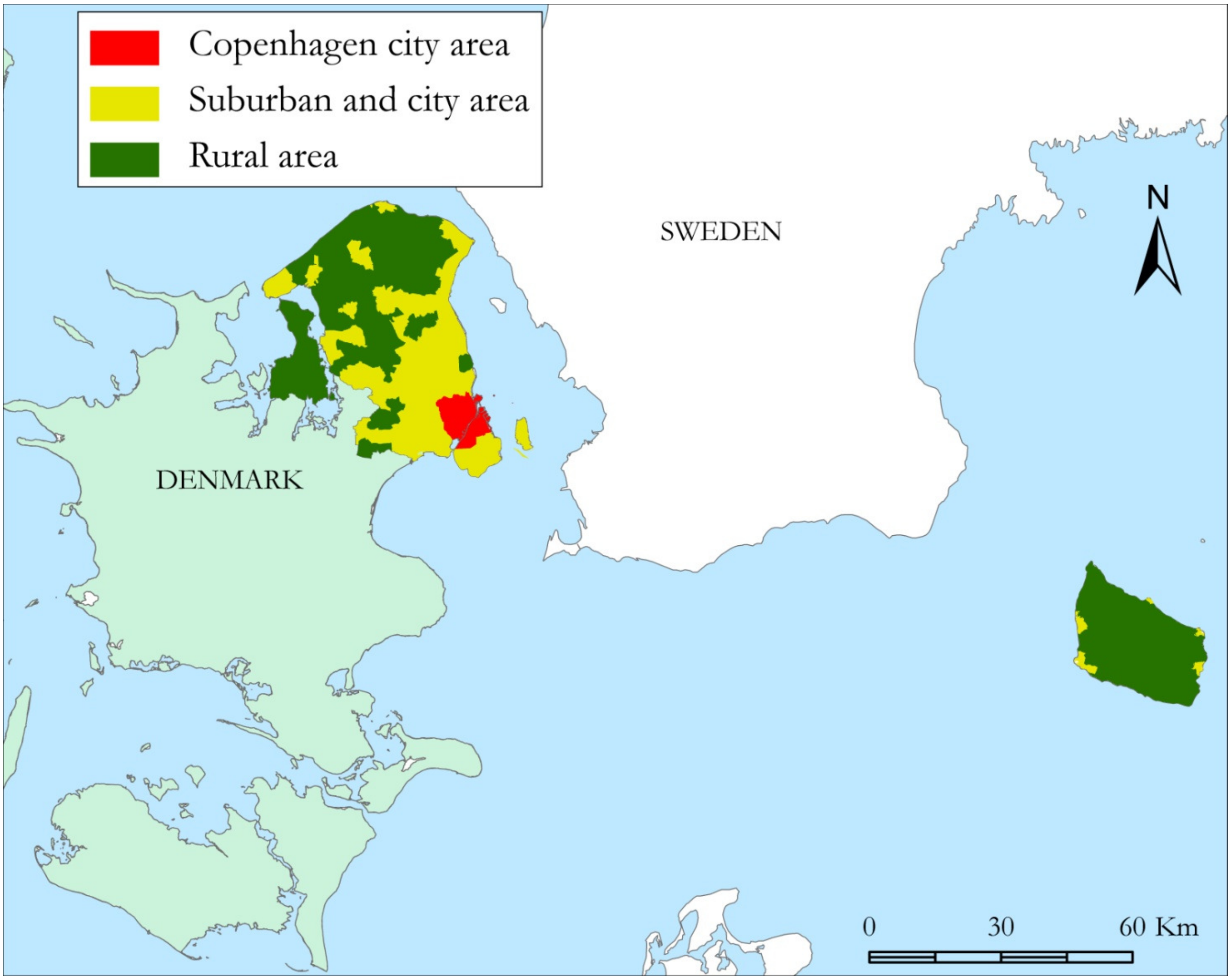

Figure 1. The Capital Region of Denmark divided into 3 zones based on population. The red zone shows Copenhagen and Frederiksberg Municipalities, the main Municipalities in the Copenhagen city area. The yellow zone shows parishes outside Copenhagen and Frederiksberg Municipalities with more than 250 inhabitants per km^2 and comprises Copenhagen suburban zone and cities outside Copenhagen. The green zone shows parishes with 250 or less inhabitants per km^2 and is here defined as the rural zone in the Capital Region of Denmark.

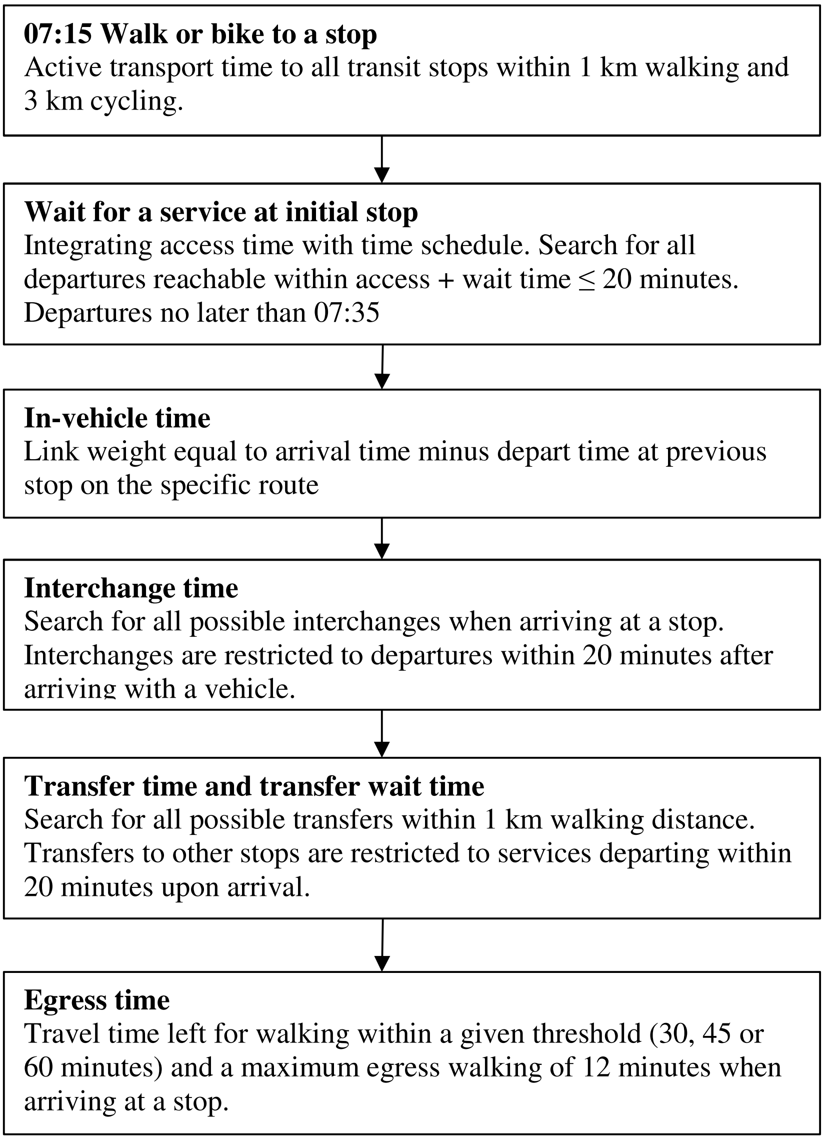

Figure 2. The door-to-door travel approach highlighting the different elements of travel time in a multimodal public transportation network model.

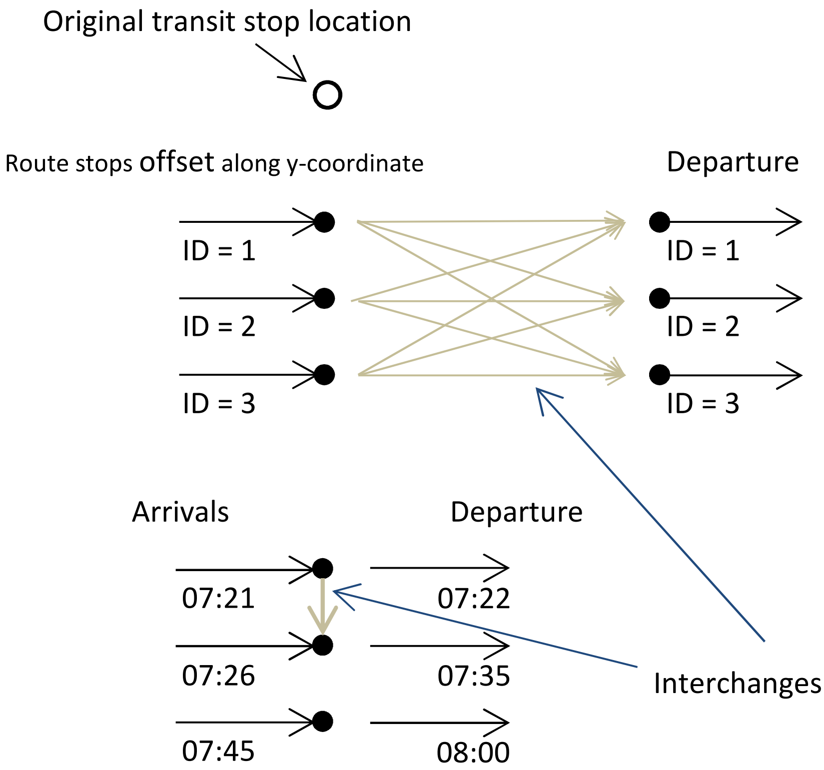

Figure 3. The splitting of a transit stop into route stops. The stops are relocated from the original location by off-setting the x or y-coordinate. Unique routes arrive at unique stops. The design enables interchanges between the new stops. All possible interchanges between stops at a public transport stop are reduced in the model (bottom) that only includes interchanges between departures no later than 20 minutes after an arrival.

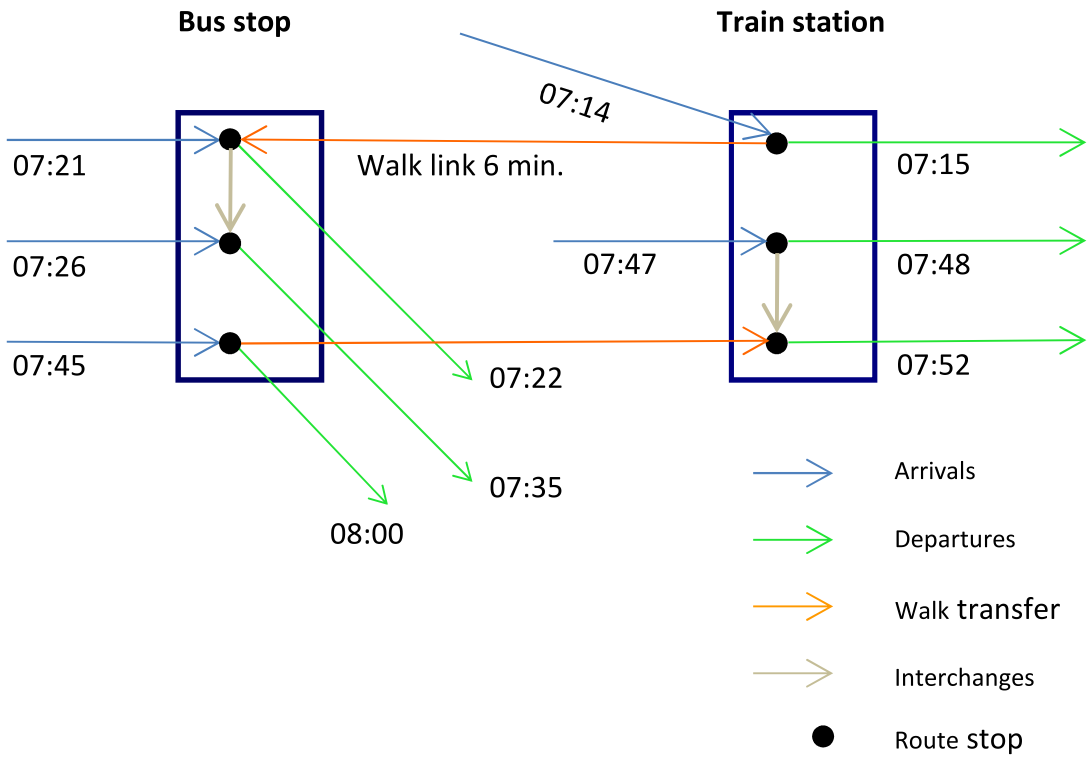

Figure 4. Interchanges at a public transportation stop and transfer between stops using walk lines of 6 minutes duration equal to 500 meter walking. Arriving by train at the train station at 7:14 gives the commuter the opportunity to shift to a bus (departing 7:22) by walking 6 minutes from the train station to the bus stop and wait 2 minutes, which equals a transfer time of 8 minutes in total.

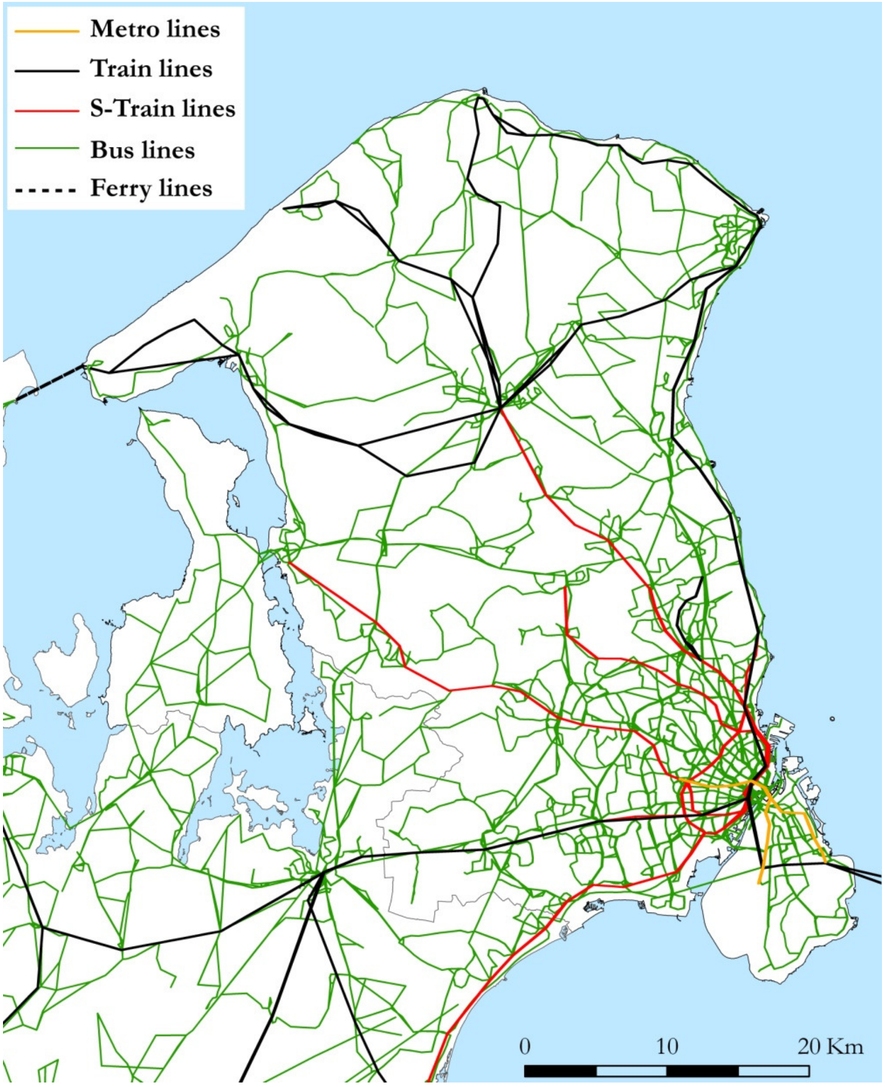

Figure 5. The constructed multimodal network showing all routes (bus, S-train, train, metro and ferry) active between 07:15 and 08:15 on a Monday morning in the Capital Region of Denmark.

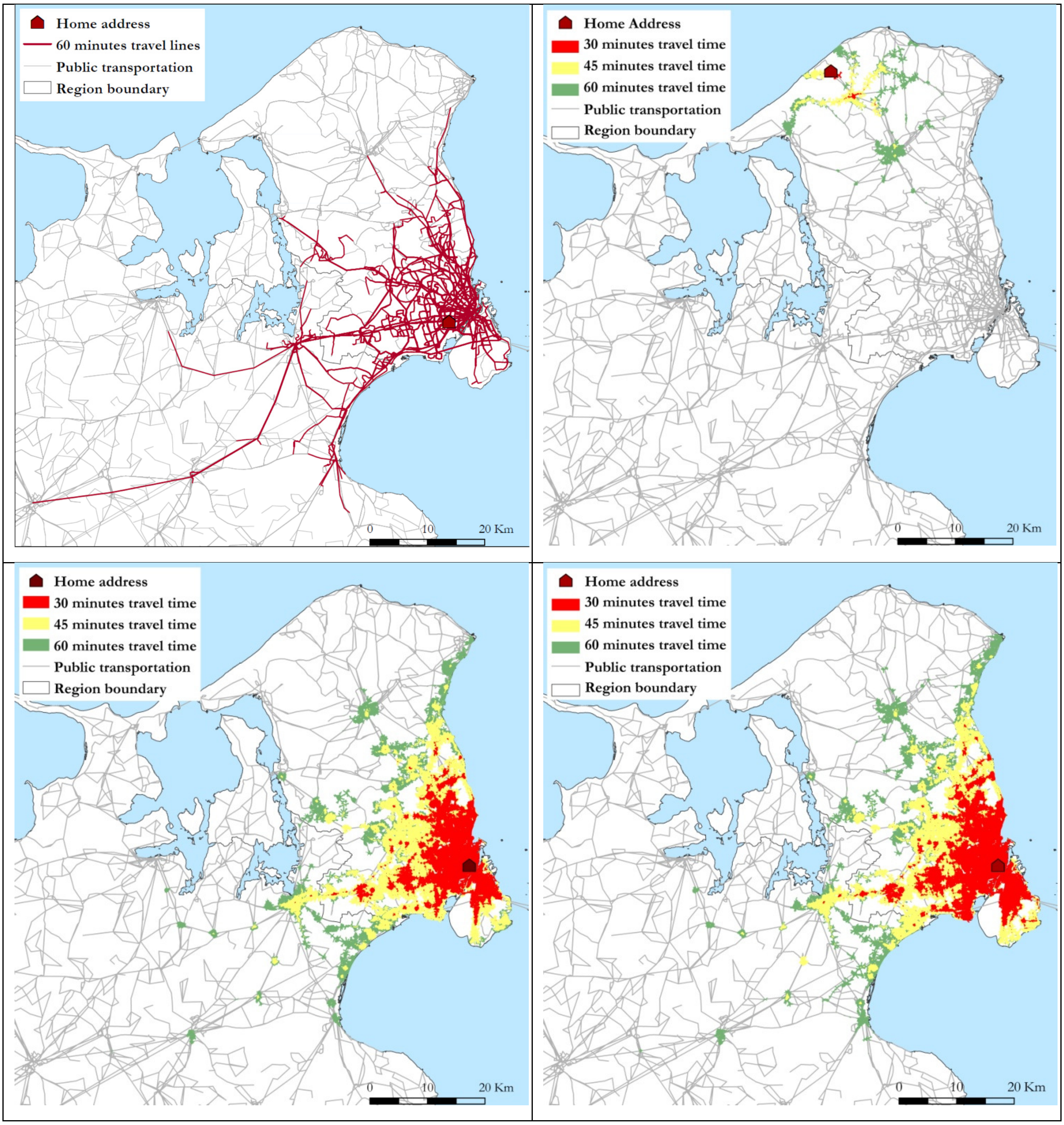

Figure 6a: Individual travel routes by public transportation using services at the nearest stop. 6b: Accessibility area resulting from travelling 30, 45, and 60 minutes using public transportation services at stops within 1 km walking distance in a rural setting. 6c and 6d: Accessibility area resulting from travelling 30, 45, and 60 minutes using public transportation services at the nearest stop and at stops within 1 km walking distance in the Copenhagen city centre.

A6: Paper III: Djurhuus, S., Hansen, H.S., Aadahl, M., Glümer, C.

Individual public transportation accessibility is associated with self-reported active commuting (submitted to Frontiers in Public health), September 2014.

Original Research
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Individual public transportation accessibility is positively associated with self-reported active commuting

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Keywords: physical activity$_1$, GIS$_2$, travel planner$_3$, multimodal network$_4$, multilevel regression$_5$.

Abstract

Background: Active commuters have lower risk of chronic disease. Understanding which of the, to some extent, modifiable characteristics of public transportation that facilitate its use is thus important in a public health perspective. The aim of the study was to examine the association between individual public transportation accessibility and self-reported active commuting, and whether the associations varied with commute distance, age and gender.
Methods: 28,928 commuters in the Capital Region of Denmark reported self-reported time spent either walking or cycling to work or study each day and the distance to work or study. Data were obtained from the Danish National Health Survey collected in February to April 2010. Individual accessibility by public transportation was calculated using a multimodal network in a GIS. Multilevel logistic regression was used to analyze the association between accessibility, expressed as access area, and being an active commuter.
Results: Public transport accessibility area based on all stops within walking and cycling distance was positively associated with being an active commuter. Distance to work, age and gender modified the associations. Residing within 10 km commuting distance and in areas of high accessibility was associated with being an active commuter and meeting the recommendations of physical activity. For the respondents above 29 years, Individual public transportation accessibility was positively associated with being an active commuter. Women having high accessibility had significantly higher odds of being an active commuter compared to having a low accessibility. For men the associations were insignificant.
Conclusions: This study extends the knowledge about the driving forces of using public transportation for commuting by examining the individual public transportation accessibility. Findings suggest that transportation accessibility supports active commuting and planning of improved public transit accessibility has thus a potential of providing health benefits to commuters.

1. Introduction

A number of studies have found that active commuters have lower risks of a number of chronic diseases (1-4). Using public transportation involves walking or cycling to a transit stop, transfer walks and walking to the end destination, thereby providing health benefits through regular physical activity to commuters during the week (5). Increasing the number of active commuters as an alternative to car-based commuting also has the beneficial potential of decreasing air pollution by lowering car congestion. Understanding which of the, to some extent, modifiable characteristics of public transportation that facilitate its use is thus important in a public health perspective.

Several studies have investigated the association between local access to public transportation stops and active commuting. Individual access to public transportation described by the proximity (6;7) and density of transit stops (8-11) as well as the service frequency and number of routes at nearest stop (7) was found to be positively associated with active commuting. The access is very important because it determines how easily a person can reach the public transportation network, however is does not quantify the accessibility by public transportation, i.e. the area and thereby opportunities than can be reached by using public transportation.

Dalvi and Martin (1978) (12) defined accessibility as the ease with which people can reach their destinations or activity sites. Thus accessibility by public transportation describes how efficient the public transportation network is in bringing people to destinations often within a given time frame and is a widely used term in transport planning and studies of urban form. Several researchers' have modelled individual public transportation accessibility (13-19). These models vary in complexity and some include time schedules while others rely on simplifications of the different parts of the journey e.g. access, waiting, in-vehicle, transfer and the egress time from the origin to destinations. Only one study has investigated individual public transportation accessibility in relation to active commuting. Frank et al. (2010) (20) found that transit accessibility was significantly associated with walk energy expenditure. Their accessibility measure described a travel survey households´ potential to reach the region's five major activity centres. In addition, others studies on travel mode choice have found that the prevalence for car-based commuting increases with distance to work (7;21;22) and that there is higher prevalence for using public transportation in younger age groups (4;23). More studies on accessibility and the association to active commuting are warranted to understand how the local public transportation is influencing active commuting.

The aim of this study was to model individual accessibility using data from a travel planner and to examine the association between individual public transportation accessibility and self-reported active commuting in The Capital Region of Denmark. Furthermore the aim was to examine if the associations were modified by the individual commute distance, age and gender.

2. Materials and methods

2.1. Study population

The study included cross-sectional data collected from the Danish National Health Survey 2010 described in Christensen et al. (2012) (24). The survey contained questions on health behavior, including distance to and time spent walking or cycling to work or study each day. Respondents either completed an enclosed paper questionnaire and returning it by the mail, or online. The Capital Region of Denmark was selected as study area. The region includes Copenhagen metropolitan area as well as suburban and rural districts. From the total population above 16 years of age (1,355,000) a random sample of 95,150 was selected; the response rate was 52.3%. The data were collected from February to April 2010. The study used a subsample of 28,928 respondents living on the main island of Zealand in The Capital Region of Denmark, working or in education, between 16 and 64 years of age and with valid answers on time spent each day on active commuting in hours and minutes and individual distance to work or study. All individuals home addresses were geocoded using address matching with the official address register from the Danish Geodata Agency.

The survey was approved by the Danish Data Protection Agency. Approval from the regional Committee on Health Research Ethics was not necessary as no human biological material was included in the data collection.

2.2. Geographical data

Public transport network data were obtained from Rejseplanen.dk which is the official Danish travel planner search engine. The data contained information on transport mode (bus, train, s-train, metro and ferry), routes, schedules and geographic location of all transit stops. The schedules covered the same period as the Health Survey i.e. February to April 2010. Road networks were obtained from the Danish Geodata agency (Kort10). Roads where walking or cycling was prohibited (e.g. motorways, highways) were excluded from the dataset before analysis.

2.3. Multimodal public transportation network

The geographic location of the transit stops and schedules from Rejseplanen.dk were used to construct a multi-modal transit network including all transport modes in the region (bus, trains, S-trains, metro and ferry). In addition, road network walk links were constructed using origin-destination matrices in the Network Analyst application of ESRI ArcGIS 10.1 (Redlands, CA: Environmental Systems Research Institute) from each individual home address to all public transport stops within 3 km. Walk links were also constructed between all stops not connected by a transit service to allow transfers not included in the transit network. The walk links connected stops situated no more than 1 km road network distance apart. Time spent along the access and transfer walk links were calculated from their distance and a walking speed of 5 km/h. Wait time at initial stop, in-vehicle, transfer and egress time was integrated in the model using the time schedule. The Network Analyst application of ESRI ArcGIS 10.1 (Redlands, CA: Environmental Systems Research Institute) was used to build the network having travel time as the network impedance. The interchange connections at the same stop/station at a given time and transfers were restricted by having an arrival time less than and within 20 minutes from the next the departure time (wait time).

2.4. Active commuting

The outcome variable was based on the self-reported time spent walking or cycling to work every day (hours, minutes) (25). The variable was dichotomized to being an active commuter binary variable ("yes" or "no"), with a cut-off value of 4 minute spent on active commuting per day and meeting recommended levels of physical activity ("yes" or "no") (≥ 30 minutes) by active commuting alone.

2.5. Individual public transportation accessibility

The individual accessibility was defined as the area each respondent can cover on the road network using active transport modes including public transportation inspired by Benenson et al., (2011) (13). The accessibility was calculated for a Monday morning between 07:15 and 08:15 during a normal week in March 2010. If no service was active within 20 minutes at the initial stop, the accessibility area was set equal to zero. Three measures of accessibility were created using public transportation services at 1) nearest stop within 1 km, 2) all stops within 1 km walking distance from home address and 3) all stops within 3 km cycling distance from home address. Services at the nearest stop do not always have the best service which is why all stops within walking distance were modelled. The 3 km access was used to capture accessibility for respondents living in the rural areas. Furthermore the accessibility area was calculated for 30 and 60 minutes travel time. This was based on the assumption that 30 minutes travel time measures local accessibility whereas 60 minutes travel time measures the regional accessibility. The 30 and 60 minutes travel thresholds has been used in a number of other accessibility studies (14;26;27). The accessible area from a given origin (AAo) can be expressed as $AAo = Aac + Aegr$. Aac is the initial access area resulting from either 1 km walking or 3 km cycling (road network) in all directions from the individual home address. $Aegr$ is the sum of egress areas resulting from walking away from all reachable transit stops in all directions on the road network.

Access and egress areas were dissolved by individual to remove overlapping areas. Individual public transportation accessibility area based on all stops within walking distance (1 km) for an individual living in Copenhagen City Center is shown in Figure 1. Ultimately the resultant accessibility areas where divided into quartiles for each measure.

FIGURE 1 HERE

2.6. Covariates

The individual covariates were obtained from central registers and comprised age, gender, income and education level. Four classes of education level were defined: primary or secondary school, vocational education, academy or bachelor degree, and master's or PhD degree.

Contextual covariates (median income level, population density and street connectivity) were aggregated by parishes, the smallest administrative units in Denmark. Street connectivity was defined by the gamma index $\gamma = l/(3(n - 2)$, where n equals the intersections (28).

2.7. Statistical analyses

SAS version 9.3 (SAS Institute, Inc., Cary, North Carolina) was used to perform multilevel regression analyses (GLIMMIX procedure) to investigate if the individual public transportation accessibility was associated with being an active commuter. A two-level model was fitted with individuals (level 1, n = 28,928) nested within parishes (Level 2, n = 223).

Two empty models were estimated to detect whether there was a contextual dimension to being an active commuter and meeting recommended levels of active commuting. A 3-step modelling strategy was used and ICC was calculated for each model: (1) The determinant was included in the model; (2) the individual level covariates were included to examine whether the between-parish variance was attributable to a compositional effect; (3) the parish level covariates were included to explore if the remaining between-parish variance could be explained by contextual factors. Furthermore subgroup analyses was conducted for distance to work expressed by living within four distance categories (≤ 5km, 5- 10 km, 10 -20 km and > 20 km) from work, for age categorized in three age categories (16-29, 30-45 and 45- 64 years of age) and for gender. Values of $p < 0.05$ were considered statistically significant. If an interaction was present, the odds of being an active commuter when belonging to a given distance or age category were calculated based on the full model.

3. Results

Table 1 shows the descriptive statistics for the study population. 56.3 % were females whilst 40.3% were between 45 and 64 years of age, 22.6 % were between 16 and 29 and 37.2 % were between 30 and 45 years of age. Approximately 73 % of the study population reported daily active commuting and 50.6 % reported meeting recommended levels of physical activity by active commuting (moderate physical activity). The proportion of active commuters decreased with increasing commute distance and age.

Table 1 Deskriptive statistics of the study population socio-demographics, home address location and commute distance by subgroups of being an active commuter and meeting recommended levels of physical activity.

	Total	**Active commuter (> 4min/day)**		**Meeting recommended levels of physical activity (≥ 30min/day)**	
		Yes	**No**	**Yes**	**No**
	N (%)	N (%)	N (%)	N (%)	N (%)
Total population	29447 (100.0)	21,480 (72.9)	7967 (27.1)	14,902 (50.6)	14,545 (49.4)
Age (average years/SD)	41.0 (13.1)	39.7 (13.6)	44.4 (11.3)	39.3 (13.8)	42.7 (12.3)
Age groups (6 missing)					
16 - 29 years	6643 (22.6)	5811 (87.5)	832 (12.5)	4306 (64.8)	2337 (35.2)
30 - 45 years	10,940 (37.1)	7630 (69.7)	3310 (30.3)	5142 (47.0)	5798 (53.0)
46 - 64 years	11,858 (40.3)	8034 (67.8)	3824 (32.2)	5451 (46.0)	6407 (54.0)
Gender (6 missing)					
Male	12,866 (43.7)	8692 (67.6)	4174 (32.4)	5837 (45.4)	7029 (54.6)
Female	16,575 (56.3)	12,783 (77.1)	3792 (22.9)	9062 (54.7)	7513 (45.3)
Education (438 missing)					
Primary or secondary school	8354 (28.4)	6587 (78.8)	1767 (21.2)	4720 (56.5)	3634 (43.5)
Vocational education	7882 (26.8)	5014 (63.6)	2868 (36.4)	3335 (42.3)	4547 (57.7)
Bachelor degree	7993 (27.1)	5894 (73.7)	2099 (26.3)	4044 (50.6)	3949 (49.4)
Master or PhD degree	4780 (16.2)	3643 (76.2)	1137 (23.8)	2534 (53.0)	2246 (47.0)
Home address location					
Copenhagen inner-city	9450 (32.1)	8183 (86.6)	1267 (13.4)	6520 (69.0)	2930 (31.0)
Suburban and city areas	17,768 (60.3)	12,105 (68.1)	5663 (31.9)	7741 (43.6)	10,027 (56.4)
Rural	2229 (7.6)	1192 (53.5)	1037 (46.5)	641 (28.8)	1588 (71.2)
Distance to work groups					
0 - 5 km	9460 (32.1)	8133 (86.0)	1327 (14.0)	5854 (61.9)	3606 (38.1)
5 - 10 km	6805 (23.1)	5217 (76.7)	1588 (23.3)	4074 (59.9)	2731 (40.1)
10 - 20 km	6604 (22.4)	4326 (65.5)	2278 (34.5)	2769 (41.9)	3835 (58.1)
> 20 km	6578 (22.4)	3804 (57.8)	2774 (42.2)	2205 (33.5)	4373 (66.5)

The ICC in the two empty models showed a noticeable significant between neighborhood variation of 13.6% in being an active commuter and 12.7 % in meeting recommendations of physical activity. The ICC in the unadjusted models ranged from 3.7 to 11.5 and was significantly reduced to 1.2 – 1.4 % in the fully adjusted models.

Table 2 shows the individual public transportation accessibility area size divided in quartiles for a travel time of 30 and 60 minutes. Changing the access point to the transit network from the nearest stop to all stops within 1 km increases the accessibility area in each quartile. Expanding the access to all stops within 3 km cycling, results in a maximum accessibility area of 713.3 km^2 when the travel time is 60 minutes.

Table 2 Quartiles of individual public transportation accessibility area for 30 and 60 minutes travel time calculated for all adult commuters aged 16 to 64 in The Capital Region of Denmark participating in the Danish National Health Survey 2010.

	30 minutes travel (km^2)	60 minutes travel (km^2)
Nearest stop		
Low	0 - 4.0	0 - 108.5
Medium low	4.1 - 19.3	108.6 - 313.7
Medium high	19.4 - 62.8	313.8 - 470.4
High	62.9 - 209.2	470.5 - 695.0
All stops within 1 km walking		
Low	0 - 16.9	0 - 264.3
Medium low	17.0 - 44.5	264.4 - 421.2
Medium high	44.6 - 85.1	421.4 - 525.5
High	85.2 - 235.8	525.6 - 695.1
All stops within 3 km cycling		
Low	0 - 42.0	0 - 383.2
Medium low	42.1 - 91.8	383.3 - 514.7
Medium high	91.9 - 137.9	514.8 - 606.4
High	138.0 - 235.9	606.5 - 713.3

The results from the multilevel regression models are shown in Table 3. No significant association was found between public transportation accessibility at nearest stop and being an active commuter. The accessibility areas resulting from accessing all stops within walking distance were significantly positively associated with being an active commuter. An increase in accessibility area was associated with significantly higher odds of being an active commuter. The same dose-response relationship as was observed in the association between the accessibility area resulting from accessing all stops within cycling distance and being an active commuter although there was no difference in odds of being an active commuter in the medium-low and the medium-high accessibility groups. In addition, Positive associations were found between the density accessibility areas and meeting recommendations on physical activity although less pronounced compared to the associations with being an active commuter

Table 3 Crude and adjusted associations (OR) between individual public transportation accessibility area and being an active commuter and meeting recommended levels of physical activity. Between neighbourhood variation is expressed by Intra-class correlation coefficient (ICC). Significant associations are highlighted in bold text.

	Active commuter (> 4min/day)		**Meeting recommended levels of physical activity (≥ 30min/day)**	
	Model 1: Crude OR (CI)	**Model 3: Fully adjusted model** OR (CI)[a]	**Model 1: Crude** OR (CI)	**Model 3: Fully adjusted model** OR (CI)[a]
Nearest stop 30 min. Acc.				
Low	1.00	1.00	1.00	1.00
Medium low	**0.92 (0.85 - 1.00)**	0.93 (0.86 - 1.01)	**0.92 (0.86 - 1.00)**	0.93 (0.87 - 1.01)
Medium high	1.05 (0.96 - 1.14)	1.03 (0.94 - 1.12)	0.99 (0.91 - 1.06)	0.98 (0.91 - 1.06)
High	**1.21 (1.10 - 1.34)**	1.05 (0.95 - 1.17)	1.03 (0.95 - 1.12)	0.97 (0.89 - 1.05)
P-value[b]	<.0001	0.0607	0.0832	0.3233
ICC	11.6	1.4	*11.8*	*1.3*
Nearest stop 60 min. Acc.				
Low	1.00	1.00	1.00	1.00
Medium low	1.00 (0.92 - 1.09)	1.04 (0.96 - 1.13)	0.99 (0.92 - 1.08)	1.03 (0.95 - 1.12)
Medium high	1.07 (0.98 - 1.17)	1.03 (0.95 - 1.13)	1.03 (0.95 - 1.12)	1.04 (0.96 - 1.12)
High	**1.27 (1.14 - 1.41)**	1.07 (0.96 - 1.19)	1.04 (0.94 - 1.14)	0.97 (0.88 - 1.06)
P-value[b]	0.0002	0.6310	0.7908	0.4248
ICC	11.4	1.4	12.3	1.4
Stops within 1 km 30 min. Acc.				
Low	1.00	1.00	1.00	1.00
Medium low	**1.26 (1.16 - 1.37)**	**1.17 (1.08 - 1.27)**	**1.17 (1.08 - 1.26)**	**1.10 (1.02 - 1.19)**
Medium high	**1.70 (1.54 - 1.87)**	**1.33 (1.21 - 1.47)**	**1.41 (1.29 - 1.55)**	**1.22 (1.11 - 1.33)**
High	**2.13 (1.90 - 2.39)**	**1.37 (1.21 - 1.55)**	**1.48 (1.33 - 1.64)**	**1.15 (1.03 - 1.28)**
P-value[b]	<0.0001	<0.0001	<.0001	0.0005
ICC	6.2	1.2	8.4	1.1
Stops within 1 km 60 min. Acc.				
Low	1.00	1.00	1.00	1.00
Medium low	**1.41 (1.28 - 1.54)**	**1.17 (1.07 - 1.28)**	**1.43 (1.31 - 1.57)**	**1.23 (1.12 - 1.34)**
Medium high	**1.90 (1.71 - 2.11)**	**1.34 (1.21 - 1.49)**	**1.82 (1.64 - 2.01)**	**1.37 (1.24 - 1.51)**
High	**2.73 (2.41 - 3.10)**	**1.44 (1.26 - 1.66)**	**2.17 (1.93 - 2.44)**	**1.36 (1.21 - 1.53)**
P-value[b]	<0.0001	<0.0001	<.0001	<.0001
ICC	4.8	1.3	5.3	0.9
Stops within 3 km 30 min. Acc.				
Low	1.00	1.00	1.00	1.00
Medium low	**1.62 (1.45 - 1.81)**	**1.21 (1.09 - 1.35)**	**1.58 (1.42 - 1.76)**	**1.18 (1.07 - 1.30)**
Medium high	**2.20 (1.95 - 2.49)**	**1.20 (1.06 - 1.36)**	**2.37 (2.12 - 2.66)**	**1.33 (1.19 - 1.49)**
High	**3.36 (2.94 - 3.84)**	**1.44 (1.24 - 1.67)**	**3.03 (2.69 - 3.42)**	**1.42 (1.25 - 1.61)**
P-value[b]	<0.0001	<0.0001	<.0001	<.0001
ICC	4.2	1.3	3.6	0.9
Stops within 1 km 60 min. Acc.				
Low	1.00	1.00	1.00	1.00
Medium low	**1.61 (1.44 - 1.80)**	**1.20 (1.07 - 1.33)**	**1.68 (1.51 - 1.87)**	**1.24 (1.12 - 1.37)**
Medium high	**1.98 (1.76 - 2.23)**	**1.19 (1.05 - 1.34)**	**2.11 (1.88 - 2.36)**	**1.28 (1.15 - 1.43)**
High	**3.60 (3.15 - 4.13)**	**1.45 (1.24 - 1.71)**	**3.29 (2.92 - 3.72)**	**1.47 (1.28 - 1.69)**
P-value[b]	<0.0001	<0.0001	<.0001	<.0001
ICC	3.8	1.3	3.3	0.9

[a]Adjusted for individual age, gender, education, distance to work and neighborhood median income, population density and street connectivity.
[b] P-value from type III test of the association.

The interaction between the public transportation accessibility area and categorized commute distance was significant for all measures of accessibility (p-values <0.0001) as shown in Table 4.

Table 4 OR table for associations between public transport accessibility and being an active commuter modified by commute distance. Significant associations are highlighted in bold text.

	≤ 5 km OR (Cl)	5 - 10 km OR (Cl)	10 - 20 km OR (Cl)	> 20 km OR (Cl)
Nearest stop 30 minutes Acc.				
Low	1.00	1.00	1.00	1.00
Medium low	0.99 (0.84 - 1.18)	0.96 (0.81 - 1.13)	0.82 (0.71 - 0.95)	0.94 (0.82 - 1.06)
Medium high	1.06 (0.89 - 1.26)	**1.20 (1.02 - 1.42)**	0.88 (0.76 - 1.02)	0.99 (0.85 - 1.15)
High	**1.43 (1.19 - 1.72)**	**1.21 (1.02 - 1.44)**	0.87 (0.73 - 1.03)	**0.75 (0.62 - 0.91)**
P-Value interaction = <0.0001				
Nearest stop 60 minutes Acc.				
Low	1.00	1.00	1.00	1.00
Medium low	0.96 (0.81 - 1.14)	1.06 (0.89 - 1.26)	0.93 (0.80 - 1.07)	1.15 (1.01 - 1.31)
Medium high	1.08 (0.91 - 1.28)	1.15 (0.97 - 1.35)	0.92 (0.79 - 1.07)	1.00 (0.86 - 1.16)
High	**1.43 (1.19 - 1.73)**	**1.24 (1.03 - 1.48)**	0.84 (0.70 - 1.01)	**0.74 (0.61 - 0.89)**
P-Value interaction = <0.0001				
Stops within walking distance 30 minutes Acc. (1 km)				
Low	1.00	1.00	1.00	1.00
Medium low	**1.24 (1.04 - 1.47)**	**1.23 (1.03 - 1.46)**	**1.20 (1.04 - 1.38)**	1.08 (0.95 - 1.22)
Medium high	**1.53 (1.28 - 1.83)**	**1.37 (1.15 - 1.63)**	**1.34 (1.15 - 1.56)**	**1.24 (1.05 - 1.46)**
High	**1.89 (1.55 - 2.31)**	**1.63 (1.34 - 1.98)**	1.19 (0.99 - 1.44)	0.86 (0.71 - 1.05)
P-Value interaction = <0.0001				
Stops within walking distance 60 minutes Acc. (1 km)				
Low	1.00	1.00	1.00	1.00
Medium low	**1.31 (1.10 - 1.56)**	**1.26 (1.05 - 1.50)**	**1.25 (1.08 - 1.44)**	1.05 (0.92 - 1.20)
Medium high	**1.53 (1.27 - 1.83)**	**1.49 (1.24 - 1.79)**	**1.38 (1.18 - 1.62)**	1.18 (1.00 - 1.39)
High	**2.20 (1.78 - 2.72)**	**1.72 (1.40 - 2.12)**	**1.29 (1.06 - 1.58)**	0.88 (0.72 - 1.08)
P-Value interaction = <0.0001				
Stops within walking distance 30 minutes Acc. (3km)				
Low	1.00	1.00	1.00	1.00
Medium low	1.12 (0.93 - 1.36)	**1.23 (1.01 - 1.48)**	**1.40 (1.20 - 1.63)**	**1.18 (1.02 - 1.36)**
Medium high	**1.32 (1.08 - 1.60)**	**1.38 (1.14 - 1.67)**	**1.33 (1.12 - 1.59)**	0.86 (0.71 - 1.03)
High	**1.95 (1.56 - 2.43)**	**1.78 (1.43 - 2.22)**	**1.30 (1.06 - 1.60)**	0.82 (0.66 - 1.02)
P-Value interaction = <0.0001				
Stops within walking distance 60 minutes Acc. (3 km)				
Low	1.00	1.00	1.00	1.00
Medium low	1.16 (0.96 - 1.40)	**1.25 (1.03 - 1.51)**	**1.41 (1.20 - 1.65)**	1.11 (0.96 - 1.29)
Medium high	**1.26 (1.04 - 1.52)**	**1.37 (1.13 - 1.66)**	**1.34 (1.13 - 1.59)**	0.94 (0.79 - 1.12)
High	**2.11 (1.68 - 2.66)**	**1.99 (1.58 - 2.50)**	**1.25 (1.01 - 1.56)**	**0.77 (0.61 - 0.96)**
P-Value interaction = <0.0001				

For the accessibility areas resulting from 1 km walking or 3 km cycling, an increase in accessibility area was associated with significantly higher odds of being an active commuter. For commuters having between 10 and 20 km commute distance, an increase in the accessibility area (1 km walking and 3 km cycling) was associated with significantly higher odds of being an active commuter in the medium-low quartile of accessibility compared to low accessibility. Living more than 20 km from work, the association between public transportation accessibility and being an active commuter became insignificant and even negative for medium high and high accessibility in the model with all stops within 3 km cycling. Positive significant associations were also found between all density measures and meeting recommendations of physical activity for participants with commute distance of ≤ 10 km. The associations were strongest for those having between 5 and 10 km commute distance. For participants having between 10 and 20 km commute distance, a medium-low or medium-high accessibility based on 1 km walking or 3 km cycling was associated with significantly higher odds of meeting recommendations of physical activity compared to having low public transportation accessibility. For those having more than 20 km commute distance, accessibility area was not associated with meeting recommended levels of physical activity.

The subgroup analysis with age showed that for the age category 16 to 29 years, the association between accessibility (1 km walking and 3 km cycling) and being an active commuter was insignificant. For the respondents in the other two age groups, 30 – 45 and 46 – 64 years, the accessibility was positively associated with being an active commuter. The association was strongest among the 30 to 45-year-old. The subgroup analysis with age showed the same results with meeting recommended levels of physical activity.

For women there was a significant positive association between accessibility area based on all stops within walking and cycling distance and being an active commuter. Furthermore women having high accessibility based on services at the nearest stop (30 and 60 minutes) had significantly higher odds of being an active commuter compared to the reference group (low). For men the associations were insignificant. For women there was a significantly positive association between accessibility area based on all stops within walking and cycling distance and meeting recommendations of physical activity. No significant associations were found for women between accessibility based on services at the nearest stop (30 and 60 minutes) and meeting recommendations of physical activity. For men the associations were less pronounced, although suggesting that higher accessibility based on walking and cycling was positively associated with meeting recommendations of physical activity.

4. Discussion

The findings suggest that individual public transportation accessibility influences commuters travel preferences and higher public transportation accessibility is associated with being an active commuter and meeting recommended levels of physical activity from active commuting only. The study extend the previous studies of the access to public transportation and associated active commuting by combining the access to public transportation i.e. density of stops, service frequency and available routes with the efficiency of the public transportation network in enabling the respondent in reaching destinations.

Those living in the metropolitan and inner suburban areas often have multiple transit stops within walking distance that provide different transit services and modes. The insignificant association found between individual public transportation accessibility and active commuting for public transportation accessibility at the nearest stop may thus be explained by the fact that the nearest stop provides a too simplified picture of the “real” public transportation accessibility. Another explanation may be due to the way the accessibility is modelled. The nearest stop measure is quite sensitive to services leaving between the time a participant enters the stop until the last allowed departure time at

07:35. This can result in accessibility areas of 0 km2 although services may leave at 07:36 and thereby lower the variance of the measure. Commuters tend to optimise their trip by entering a station just in time for the service to depart. This cannot be captured in this analysis.

The positive association found between accessibility based on all stops within walking distance (1 km) and active commuting reflect other findings that accessible and efficient public transportation is conducive for being an active commuter (7-11;20).

In Accordance with other studies we found that distance to work or study influence active commuting (7;21;22). Living close to work (within 10 km) in areas of high public transportation accessibility are associated with being an active commuter. Metropolitan and city areas have high public transportation accessibility, high density of opportunities such as jobs and a supportive infrastructure that promotes walking or cycling and use of public transportation. There is prevalence for car-based commuting at commute distances longer than 20 km even if public transportation accessibility is high resulting in a negative association between public transportation accessibility and active commuting.

A high proportion of the respondents between 16 and 29 live close to their work or study and walk or cycle all the way. This weakens the effect of public transportation (the association is insignificant) although other studies find that this age group is the most inclined to use public transportation to travel (4;23). For the other age groups, the positive associations found reflect that using active commute modes becomes more attractive if the potential for reaching other destinations is high.

The results suggest that men's active commute patterns are less influenced by public transportation than women which may be caused by more car-based commuting. Living in areas of high accessibility is not associated with active commuting in men whereas women show a clear dose-respons relationship between accessibility and the odds for being an active commuter.

Higher public transportation accessibility has the potential for increasing active commuting and thereby providing important health benefits through active transportation. Future transport planning should evaluate how longer commute trips (>10 km) can be covered by better public transportation services to create an alternative to car-based commuting. Furthermore it should include restrictions on car-based commuting such as restrictions on car-park facilities which have a positive impact towards active commuting in Denmark (22).

4.1. Strengths and limitations

This study has a number of strengths. The multimodal network constructed with integrated time schedule made it possible to calculate individual public transportation accessibility based on network travel time and walking along the road network. The accessibility measure includes the potential to travel in the association analysis in contrast to just looking at the access to public transportation stops. The large study population selected from one of the largest health surveys in the world and the individual register-based socioeconomic data provide a unique study base. The multilevel model accounted for the large neighborhood effect found.

There are a number of limitations to this study. The cross-sectional design makes it impossible to draw conclusion on causality. The self-reported daily active commuting may be subject to information bias. The active commuting information is restricted to time spent walking or cycling to work or study, and it does not refer to time spent in usage of public transportation or car. The high proportion of respondents reporting active commuting in this study is substantially higher than in other studies. It is therefore unknown whether the results may be generalizable to other countries or cities where active commuting is not as common. The multimodal network uses the time schedule to calculate travel time but no information about service performance have been included. No land-use parameter such as reachable jobs is included in the individual public transportation accessibility meaning that all areas are weighted equally important when commuting. The public transportation accessibility is thus used as a measure of how efficient the public transportation system is in bringing respondents to other destinations. Transfers between transport modes were not limited in this study although this is often listed as an inconvenience when using public transportation (29). Further work would benefit from including work addresses in order to model routes to work using different transport modes and examine associated travel choices.

5. Conclusion

This study extends the knowledge about the driving forces of using public transportation for commuting by examining the individual public transportation accessibility. The findings suggest that provision of good public transportation accessibility is associated with active commuting although it varies with distance to work or study, age and gender. The implication for future transport and health policy is to improve public transit services by increasing accessibility through improved access and linkage between services and keep travel costs at a rational level.

Author contributions

All authors designed the protocol for this study. Sune Djurhuus performed the GIS and statistical analysis and drafted the manuscript. Henning Sten Hansen, Mette Aadahl and Charlotte Glümer critically revised and helped to draft the manuscript. All authors read and approved the final manuscript.

Conflicts of interest

The Authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

6. References[1]

(1) Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJ, Martin BW. Correlates of physical activity: why are some people physically active and others not? Lancet 2012 Jul 21;380(9838):258-71. doi: 10.1016/S0140-6736(12)60735-1

(2) Gordon-Larsen P, Boone-Heinonen J, Sidney S, Sternfeld B, Jacobs DR, Jr., Lewis CE. Active commuting and cardiovascular disease risk: the CARDIA study. Arch Intern Med 2009 Jul 13;169(13):1216-23. doi: 10.1001/archinternmed.2009.163

(3) Hamer M, Chida Y. Active commuting and cardiovascular risk: a meta-analytic review. Prev Med 2008 Jan;46(1):9-13. doi: 10.1016/j.ypmed.2007.03.006

(4) Laverty AA, Mindell JS, Webb EA, Millett C. Active travel to work and cardiovascular risk factors in the United kingdom. Am J Prev Med 2013 Sep;45(3):282-8. doi: 10.1016/j.amepre.2013.04.012

(5) Pratt M, Sarmiento OL, Montes F, Ogilvie D, Marcus BH, Perez LG, et al. The implications of megatrends in information and communication technology and transportation for changes

[1] Provide the doi when available, and ALL complete author names.

in global physical activity. Lancet 2012 Jul 21;380(9838):282-93. doi: 10.1016/S0140-6736(12)60736-3

(6) Coogan PF, White LF, Adler TJ, Hathaway KM, Palmer JR, Rosenberg L. Prospective study of urban form and physical activity in the Black Women's Health Study. Am J Epidemiol 2009 Nov 1;170(9):1105-17. doi: 10.1093/aje/kwp264

(7) Dalton AM, Jones AP, Panter JR, Ogilvie D. Neighbourhood, Route and Workplace-Related Environmental Characteristics Predict Adults' Mode of Travel to Work. PLoS One 2013;8(6):e67575. doi: 10.1371/journal.pone.0067575

(8) Hino AA, Reis RS, Sarmiento OL, Parra DC, Brownson RC. Built Environment and Physical Activity for Transportation in Adults from Curitiba, Brazil. J Urban Health 2013 Oct 5. doi: 10.1007/s11524-013-9831-x

(9) Li F, Harmer PA, Cardinal BJ, Bosworth M, Acock A, Johnson-Shelton D, et al. Built environment, adiposity, and physical activity in adults aged 50-75. Am J Prev Med 2008 Jul;35(1):38-46. doi: 10.1016/j.amepre.2008.03.021

(10) Lovasi GS, Neckerman KM, Quinn JW, Weiss CC, Rundle A. Effect of individual or neighborhood disadvantage on the association between neighborhood walkability and body mass index. Am J Public Health 2009 Feb;99(2):279-84. doi: 10.2105/AJPH.2008.138230

(11) McConville ME, Rodriguez DA, Clifton K, Cho G, Fleischhacker S. Disaggregate land uses and walking. Am J Prev Med 2011 Jan;40(1):25-32. doi: 10.1016/j.amepre.2010.09.023

(12) Dalvi M.Q., Martin K.M. The measurements of accessibility: some preliminary results. Transportation 1978;5:17-42.

(13) Benenson I, Martens K, Rofé Y, Kwartler A. Public transport versus private car GIS-based estimation of accessibility applied to the Tel Aviv metropolitan area. Annals of Regional Science 2011;47(3):499-515. doi: 10.1007/s00168-010-0392-6

(14) Gent C, Symonds G. Advances in public transportation accessibility assessments for development control - a proposed methodology. PTRC AnnualTransport Practitioners' Meeting, UK, 2005.

(15) Lei TL, Church RL. Mapping transit-based access: integrating GIS, routes and schedules. International Journal of Geographical Information Science 2010;24(2):283-304. doi: 10.1080/13658810902835404

(16) Liu S, Zhu X. Accessibility Analyst: an integrated GIS tool for accessibility analysis in urban transportation planning. Environment and Planning B: Planning and Design 2004;31(1):105-24. doi: 10.1068/b305

(17) Mavoa S, Witen K, McCreanor T, O'Sullivan D. GIS based destination accessibility via public transit and walking in Auckland, New Zealand. Journal of Transport Geography 2012;20:15-22. doi: 10.1016/j.trangeo.2011.10.001

(18) O'Sullivan D, Morrison A, Shearer J. Using desktop GIS for the investigation of accessibility

by public transport: an isochrone approach. International Journal of Geographical Information Science 2000;14(1):85-104.

(19) Salonen M, Toivonen T. Modelling travel time in urban networks: comparable measures for private car and public transport. Journal of Transport Geography 2013;31:143-53. doi: 10.1016/j.jtrangeo.2013.06.011

(20) Frank LD, Greenwald MJ, Winkelman S, Chapman J, Kavage S. Carbonless footprints: promoting health and climate stabilization through active transportation. Prev Med 2010 Jan;50 Suppl 1:S99-105. doi: 10.1016/j.ypmed.2009.09.025

(21) Badland HM, Schofield GM, Schluter PJ. Objectively measured commute distance: associations with actual travel modes and perceptions to place of work or study in Auckland, New Zealand. J Phys Act Health 2007 Jan;4(1):80-6.

(22) DTU. The Danish National Travel Survey. http://www.modelcenter.transport.www6.sitecore.dtu.dk/english/TU/Hovedresultater. 2013.
Ref Type: Online Source

(23) Morency C., Trépanier M., Demers M. Walking to transit: An unexpected source of physical activity. Transport Policy 2011;18:800-6. doi: 10.1016/j.tranpol.2011.03.010

(24) Christensen AI, Ekholm O, Glumer C, Andreasen AH, Hvidberg MF, Kristensen PL, et al. The Danish National Health Survey 2010. Study design and respondent characteristics. Scand J Public Health 2012 Jun;40(4):391-7. doi: 10.1177/1403494812451412

(25) Andersen LG, Groenvold M, Jorgensen T, Aadahl M. Construct validity of a revised Physical Activity Scale and testing by cognitive interviewing. Scand J Public Health 2010 Nov;38(7):707-14. doi: 10.1177/1403494810380099

(26) Kawabata M. Spatiotemporal dimensions of modal accessiblity disparity in Boston and San Francisco. Environment and Planning A 2009;41:183-98. doi: 10.1068/a4068

(27) Kawabata M, Shen Q. Job accessibility as an indicator of auto-oriented urban structure: a comparison of Boston and Los Angeles with Tokyo. Environment and Planning B: Planning and Design 2014;33:115-30. doi: 10.1068/b31144

(28) Berrigan D, Pickle LW, Dill J. Associations between street connectivity and active transportation. Int J Health Geogr 2010;9:20. doi: 10.1186/1476-072X-9-20

(29) Stone J., Mees P. Planning public transport networks in the post-petroleum era. Australien Planner 2010;47:263-71. doi: 10.1080/07293682.2010.526550

7. Figure legends

Figure 1 Individual public transportation accessibility area based on entering all stops within walking (road network) distance from home address (1 km). The shown accessibility areas results from travelling 30 and 60 minutes by public transportation in all directions starting from the home address in the Copenhagen city area at 07:15 in the morning.